BETTER UNDERSTANDING THE MODIFIERS OF DOMESTIC WATER CONSUMPTION: AN INVESTIGATION PROJECT

Presented to the Faculty

of the University of Alaska Anchorage

in partial Fulfillment of the Requirements

for the Degree of

MASTER OF PUBLIC HEALTH

By

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Anchorage, Alaska

April 2014

Abstract

Around the world different living circumstances have an enormous yet poorly quantified impact on human water consumption. Water consumption levels are in turn closely linked to health and quality of life, particularly where access to water is limited. These facts place significant water and health impacts in the hands of those who make design and implementation decisions about living circumstances – professionals who are not necessarily experts in matters of water. This investigation was an examination of the abundant yet discordant and atomized data on human water consumption, providing a summary of water consumption modifiers and water consumption numbers over a wide range of circumstances, in table form, to those involved with dwelling infrastructure, water/sanitation, hygiene, or other water-impacted fields. Disambiguation of the water consumption concept was necessary, which encompasses three categories of consumption: footprint, domestic, and ingestion. Footprint water consumption was documented to be greater than domestic consumption by an order of magnitude. Domestic consumption was found to be ~99% defined by our surroundings and to vary between 7 and 600 lpcd. Principal modifiers of domestic consumption are service level, sanitation decision (dry vs. flush), presence of metering, use of low flow fixtures, residential lot or compound size, and climate. Sanitation decision is linked to substantial health externalities. Price appeared to have a less-than-anticipated impact, due likely to social/health restraints in applying strict economic principles. Dwelling size was found not to be a modifier. Relative impact of modifiers discussed. Narrative 44,000 words; Ref. 160. *Note: An executive summary can be found at the end of this document.*

Acknowledgments

The author wishes to thank the following persons for their contributions to this investigation project: committee chair Liz Snyder for consistent and persistent coaching from beginning to end; committee members Jenny Miller, Aaron Dotson, and Craig Jaeger for thoughtful reviews; Rhonda Johnson for guidance through all the questions leading to the project; Alex Basset, Alex Jones, and Wileidy Lespin for tenacious reading and assistance with cleaning of the drafts; the interviewees for their professional insights and perspective; Cloves Amorim for thesis therapy; my father, Walter Johnson, for encouragement on the path of study at all stages of life; and my wife, Antonia Lespin, for encouragement on the path of life at all stages of study.

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Abbreviations and acronyms

AKA – Also known as

AQUASTAT – FAO water database

AWWA – American Water Works Association

AWWU – Anchorage Water and Wastewater Utility

BMI – Body mass index

CDC – Center for Disease Control

CINAHL – Cumulative Index of Nursing and Allied Health Literature

CV – contingent valuation

DALY – Disability-Adjusted Life Years

EPA – United States Environmental Protection Agency

ERS – Economic Research Service (of the USDA)

FAO – Food and Agriculture Organization (of the United Nations)

Hh -- household

INAPA – Instituto Nacional de Agua Potable y Alcantarillados [National Institute for Potable Water and Sewers] Dominican Republic

IOM – Institute of Medicine

IRB – Institutional Review Board

IRC – International Reference Centre for Water and Sanitation

JSTOR – Journal Storage (digital library)

LLET – low level equilibrium trap

lpcd – liters per capita per day (also lpcpd, lcd)

1 lpd -- liter per day = 0.365 m^3py;

1 m^3py – cubic meter per year = 2.74 lpd

MDG – Millenium Development Goal

NGO – Non-governmental organization

OECD – Organization for Economic Cooperation and Development

O&M – Operation and Maintenance

PAHO – Pan American Health Organization

REUWS – Residential End Use Water Study (North America, 1999)

SANAA – Servicio Autónomo Nacional de Acueductos y Alcantarillados [National Autonomous Water and Sewer Service] (Honduras)

SANEPAR – [Water and Sanitation Service of Parana State] Brazil

Sphere – Sphere Project Humanitarian Charter and Minimum Standards in Humanitarian Response

TDS – Total Dissolved Solids

UAA – University of Alaska Anchorage

UN – United Nations

UNDP – United Nations Development Program

USDA – United States Department of Agriculture

USGS – United States Geological Survey

UFW – unaccounted for water

VIP – ventilated improved pit [latrine]

WB – World Bank

WEDC – Water, Engineering and Development Center

WFN – Water Footprint Network

WHO – World Health Organization

WTP – willingness to pay

WWTF – Wastewater treatment facility

Prologue

In 2011, I was asked by a former colleague to accompany him to a newly constructed community in the north of Haiti to look at some difficulties with the water and sanitation infrastructure. The community, consisting of 200 new homes (~1000 residents), had been built by an international non-governmental organization (NGO) as part of the reconstruction efforts in Haiti following the 2010 earthquake.

Upon arrival in the community, it became immediately obvious that there was a disconnect between the water and sanitation system that had been envisioned by the designer/architects, engineers, and project managers on one hand, and the water and sanitation system that could be realistically supported by the community in the rural Haitian setting. Those involved in the design vision for the community were from Europe, and had transplanted what was familiar to them to the Haitian project. The community had houses that, though modest in other aspects, were supplied with full water amenities -- flush toilets, indoor showers, multiple sinks, and outside taps for watering ornamental plants -- all in a countryside where basic pit latrines were considered luxuries and water for the most essential life functions of drinking and cooking was scarce. The water related infrastructure of the project was an extremely poor fit with the context in which it was implemented.

Figure P-1. Flush toilets and ornamental plants in rural village short on water

Haiti (2011), image by the author

Projects like this are disheartening to see, but not unheard of in developing countries, where NGOs routinely operate with inadequate or no oversight. Goyet and Greigspoor (2007), in a trenchant analysis of the divide between international relief and development activities, refer to NGOs and their work as the “largest unregulated industry in the world.” NGOs, with their funding originating far from the focal point of their work, are too often able to carry out projects in poor countries without the meaningful involvement, approval of, or accountability to local authorities. Local authorities, with extremely limited resources, are not well positioned to exercise control over work done under their jurisdiction. This is a widespread complaint in the international development community, the nature of which is well portrayed in a recent Washington Post article on post-quake Haiti, where NGOs operating there were characterized by dissatisfied Haitian leaders as “an invasion” and a type of parallel government (Booth, Feb. 1, 2011).

Figure P-2. Public watering point with women waiting, 3km from described project.

Haiti (2011), image by the author

What aroused my project investigation interest were not the errors made in the design, implementation, and oversight of the project described above, however; it was the series of discussions that occurred *after* those in the sponsoring NGO realized that they had significant public health, infrastructure engineering, and community credibility problems. Exploring potential solutions (among NGO staff, community members, outside experts, and water service providers) over a two month period following the visit, it became increasingly apparent that there were material gaps and order-of-magnitude discrepancies in the understanding among multiple professional project personnel about: 1) how much water would be required to meet the needs of the community with the as-built housing infrastructure, 2) how much leeway there might be with the existing infrastructure in adapting to the limited water circumstances, 3) what might be the practical public health, social, and engineering consequences of shortfalls in meeting those needs, and 4) how much less water might be needed if the built infrastructure were changed. I realized at that point that the abundant extant data on human water consumption, far from helping bring clarity to the situation, were providing the base to exacerbate the problem.

Chapter 1: Background and context

Water is a multilevel determinant of health -- as an essential ingested substance, a hygiene agent, a cooking medium, a universal solvent, a disease vector, and a human waste carriage medium -- and more broadly, it is a determinant of quality of life. According to estimates by WHO (2004, 2013), 3.6% of the DALY global burden of disease and 1.6 million annual deaths worldwide are attributable to unsafe water supply, sanitation, and hygiene. As the world population increases and fresh water resources come under pressure and/or face contamination threats around the world, issues of the provision of adequate water for human needs, management of water consumption, and water resource conservation will have steadily increasing importance. Any research fostering a clearer understanding of human water consumption variables will be a useful tool in providing better utilization, management, and optimization of this resource.

We are all aware that as humans we need water, and physiologically, the amount needed varies little between individuals. However, it appears to be less understood and appreciated that the physical infrastructure and the context for human habitat can dramatically affect how much water we need and use: per capita domestic water consumption can vary up to 100-fold depending on the particular combination of living circumstances and water access (e.g. Sphere, 2011; WHO, 2003; Gleick, 1996). Framed this way, the infrastructure is a far more potent determinant of water consumption than one’s condition of being human. While figures have long existed establishing how much water is required to satisfy basic needs for health under a wide range of circumstances, the information is contradictory, confusing, highly fragmented, and often separated from its context and underlying assumptions, rendering it difficult to interpret, even for those that work directly in water delivery.

This deficiency in understanding can affect several kinds of projects. First, within housing projects in developing regions of the world, beneficiaries, architects, builders, project managers, foundation or funding agency staff, and community development workers can all potentially be involved with making design and construction decisions that have a profound impact on the quantity of water that each beneficiary will use. It is nowhere near certain that many or any of these stakeholders will be experts on meeting human water needs or have access to concise and coherent water consumption data that can meaningfully inform their decisions (other than following established norms, which may or may not be appropriate to the situation). Second, the same could be true for sanitation projects that are at times carried out independent from the housing infrastructure, e.g. projects for stand-alone sanitation, bathing, and washing facilities (often built long after the dwellings). Third, within hygiene promotion projects – now a major area of health work in developing countries – beneficiaries, along with community developers, educators, health promoters, and health care providers, critically depend not simply on ‘water’ for success, but on certain characteristics of that water: quantity, quality, cost, accessibility, distance, convenience, hours of availability, and reliability (e.g. Esrey et al., 1991; Kawata, 1978; Lawrence et al., 2002; McIntosh, 2003; Vairavamoorthy, 2001). When those who work in activities related to the provision of housing, water supplies, sanitation, hygiene or other health initiatives in a developing country setting are not well versed in the link between water consumption, the human habitat infrastructure, and other context factors, they risk exposing project beneficiaries to real hardships and health risks.

In concrete terms, miscalculation of real water needs or mismatch to the dwelling infrastructure, in the case of shortfall, can lead to significant problems. The list could include inconvenience in the daily routine of users, bitter social tensions and intra/inter community aggression, impaired ability to consistently meet basic needs for hygiene and health, and, where water is contemplated as the carriage vehicle for human waste, serious problems related to environmental contamination, clogged sewer operation, and waste-transmitted disease (e.g. Schoeffel, 2006; Smiley, 2011; Staddon, 2011; Gleick, 2008, Johnson, 2003).

At the other end of the spectrum, the miscalculation of water need resulting in making available more water than is necessary presents its own problems (at least when not metered). Though not well documented, it can enable egregious waste of an essential resource, can create false expectations of future availability of water (until the served population grows into or beyond the design parameters), can cause inefficient use of scarce water delivery funds, and has the potential to promote cavalier attitudes about resource conservation through the illusion of abundance. And at either end of the spectrum, disparities in water consumption between any given population and an adjacent one, even if technically necessitated by the infrastructure differences which then dictate the need level, beg fundamental issues of social justice, human dignity, and respect for natural resources -- e.g. when one community uses drinkable water for disposal of human waste while another nearby group lacks sufficient water for drinking and washing.

Chapter 2: A Review of the Literature

What we know about water consumption

Credible sources for information on human water consumption are numerous and can be broken into at least seven categories: 1) scholarly peer-reviewed articles; 2) local, state, national, and international norms or guidelines; 3) water/sanitation related textbooks; 4) professional design guides, field manuals, and handbooks; 5) project implementation documentation from water-involved entities; 6) popular press (for public perceptions related to specific water topics); and 7) commercial informational materials (for technology-related modifiers). Much of the information is in the form of secondary research, but adequate primary research/sources are available, such as municipal water consumption data or the Residential End User Water Study (REUWS; Mayer, DeOreo, Opitz, Kiefer, Davis, Dzieglelewski, and Nelson, 1999). The information provided by these sources is extensive and yet disturbingly incomplete in individual presentation. Two examples from the literature are discussed in brief below.

The Sphere Project Humanitarian Charter and Minimum Standards in Humanitarian Response (2011) is a good starting point and establishes a well-recognized floor for human water consumption: their target is 15 liters per capita per day (lcpd), reflecting basic needs for drinking, cooking, hygiene, washing, and domestic cleaning. This is an African-centric number, and with that number goes the assumption that the user of said amount of water will need to walk a considerable distance to it or, if close at hand, will wait in line to access it. Implicit is that it is likely to be drawn from a public well or tap stand. While it is a useful academic or ethical reference point – a human can indeed survive on 15 liters per day -- problems with its use as a professional or design reference begin almost from the moment it is considered. What if the distance or time to access the water source is reduced? Can people still be expected to confine their use to 15 lcpd? The answer is no, but the number 'basic 15 liters' can float about as a spuriously exact reference, completely untethered to this substantially modifying fact. Could this number be used for calculation in a village improved-water supply project? Unlikely, but the answer would depend on numerous factors. Could someone survive on less water, if the need were to arise, such as after a natural disaster? The answer is actually yes -- 15 liters is an arbitrary designation, not a physiological minimum. Emergency relief situations can and do on occasion require departure downward from the 15 liter standard (WHO, undated). The Institute of Medicine (2005) reference on adequate intake for water was just 2.7 to 3.7 liters daily and lower numbers can be found (e.g. EPA, 1976). Does the 15 liter number provide for good health? Adequate hygiene? Human waste removal? It does not take long to realize that a number like this, if separated from its context and underlying assumptions, is possibly worse than no number at all for its ability to mislead.

Peter Gleick (1996, 1999), a prominent scholar on the topic of water use and conservation, has explored human use patterns under many circumstances in an attempt to answer questions like those above. In synthesizing multiple perspectives, he has recommended 50 lcpd as the minimum acceptable level to "alleviate misery and suffering." Jacobsen (2014), in a text used for one of our own UAA public health courses, also referred to 50 lpcd as the minimum "recommended for health living". That, however, is over three times the Sphere figure. What then does this say about the Sphere Project's minimum number (or for that matter, their humanity)? At an order of magnitude greater than the lowest stated minimum amounts of water needed to sustain life (2 to 2.5 liters: WHO, 1971; EPA, 1976), does this mean the 50 lpcd figure includes a flush toilet for the user? Neither Gleick nor Jacobsen are explicit on this critical point, and a quick look at municipal water consumption data or norms for residential water consumption in modern urban settings would leave the reader in considerable doubt. Consumption data for urban water supplies can range from around twice Gleick's recommendation, at just over 100 lcpd at the lowest, to a high surpassing 500 lcpd (e.g. Walker & Velasquez, 1999; Environmental Data Compendium, 2005; Aquaterra, 2008). The 50 liter standard appears to be more generous than needed for basic survival, yet less than enough to meet the needs of the developed world living with water-driven sanitation. In the end one is left with the questions: “what do these numbers really then mean?” and going to the central concern of this investigation, “for what can they reliably be used?” The answer may be, unfortunately, “not much” – especially if you happen to be a funding, design, or field professional trying to weigh factors of water resource availability, cost, disparity, or sustainability to determine what is the best course of action in a human development setting.

The foregoing paragraphs are not meant to probe the issue beyond the point of illustrating how even commonly cited water reference figures are less useful than they may initially seem and highly prone to mislead if presented without context. Within any designation of water consumption, there are powerful modifiers of water need --

modifiers that are more significant than the reference number itself -- and which warrant better, more comprehensive, more integrated, and more accessible treatment.

What the literature does not provide

At the outset it should be acknowledged that many writings do attempt to link water consumption to one or more modifiers, often starting with distance traveled to the water source or the service level within the community of dwellings and then sometimes addressing a number of other factors such wait times or water quality in narrative form (see Fig. 9-4). For example, it is possible to find detailed scales that indicate the consumption level to expect when the water user must walk 1000 meters to a tap stand as compared to 100 meters, then with a tap in each family's yard, to a kitchen tap in each home, and compared finally to multiple taps and flush toilets in the home (e.g. Hofkes, 1983). But these scalar/spectrum data do not contemplate and certainly do not integrate more than a few of the additional variables that determine water consumption. Though a water service level scale could be found in a number of sources (such as the previously mentioned IRC, or WHO, 2003, or Gleick, 1996), it would not be easy to find information that integrates a service level scale with discussion of intermittent service delivery, metering, block pricing, or other modifiers of consumption. Water-related social issues, though capable of exerting impact on the trustworthiness of the modifiers, are generally screened off from the numerical discussion and treated separately in the literature with a more 'community development' perspective (e.g. Fonseca & Bolt 2002).

What is needed is work that draws together multiple sources to address in one place the impact of as many modifiers as possible, and to provide tables with a wider reach than a single scale. The tables in this investigation have the form of mosaic presentation of data (e.g. Table 17-A) and composites that combine data sources to build scales with better accuracy, range, and context (e.g. Table 17-C). A mathematical formula to calculate a prospective water consumption value incorporating many modifiers would be unwieldy and likely not accurate, but presenting an information-dense collection of values under differing circumstances in a simple grid can provide reference points to triangulate inferences (e.g. Table 17-H). Lastly, where possible, the underlying assumptions of consumption numbers (e.g. dry or flush sanitation) need to be visibly connected to the numbers themselves (e.g. listing assumptions in abbreviated form in the tables).

Overview of the domestic consumption modifiers of this study

First, virtually all the sources cited in this work reference the individual as the base modifier or denominator of consumption. While the individual was the most frequent denominator of water consumption and the only one applicable over the full range of water service levels, the residential dwelling – household – did occasionally appear in the literature as a denominator. Where estimated or calculated data on occupants per household is available, household based information can be converted to individual. For this study the individual was used as the denominator for ease of comparison.

Within the individual or ‘per capita’ designation there was a wide range of water consumption that is dependent on the different circumstances of each individual. In the realm of domestic water use, an individual may consume less than 7 lpcd or greater than

600 lpcd, based on factors other than the per capita. In a sense, most of the non-per-capita modifiers had a greater role in determining consumption than the individual himself or herself.

Following is a list of modifiers that were estimated to be relevant to the issue of water consumption, in either perception or fact. They have been derived from the readings in preparation for this investigation project and from long exposure of the researcher to them as issues in professional work in the water/sanitation field.

As important as the modifiers that have a documentable impact on consumption are those that are sometimes perceived to have an impact, whether or not borne out by the evidence (e.g. dwelling size). Readers could discount the data presented here if perceived modifiers that in fact have little or no impact on consumption are simply ignored rather than explained. To the extent possible they were identified, investigated, and discussed.

Water consumption modifiers investigation list

Categories of consumption (footprint, domestic, ingestion)

Water for waste carriage

Water metering

Service levels of water delivery

Collection time and distance

Conservation technology

Conservation education

Living standard

Price and fee structure

Dwelling size

Household size

Lot or compound size

Climate

Altitude and water line pressure

Traditional sources

Chapter 3: Research goals, questions, objectives

Goal

My intent for this work was to wade into the mass of discordant data on human water needs in order to develop a framework that better organizes the modifiers of direct water consumption in relation to each other and better places direct water consumption in the larger context of overall consumption. The emphasis of this work was on bringing together in one place as many modifiers as possible of direct water consumption, providing some indication of their individual and combined impact on that water consumption, and presenting the information in a way accessible and relevant to those working in water supply, in water resource conservation, in human dwelling infrastructure, or in international community development.

Key research questions

The introductory discussion of water consumption in Chapter 2 brings out questions that formed the basis of this research. These questions can be summarized into the following lines of inquiry:

1. Is the initial list of modifiers (page 17) complete?
2. What reliable information exists on the aforementioned modifiers of water consumption?
3. Which of the identified potential modifiers are of the greatest weight as it relates to decision-making, and which are of lesser weight?
4. How can the information about individual modifiers be tied together into a form that would be useful to those working on water related

public health issues, dwelling infrastructure, water resource conservation, or water and sanitation systems, particularly in developing world situations?

5. What disciplines beyond public health and engineering can inform the integration of the information found into a more readily accessible form?

Objectives

The research objectives were:

1. An in-depth investigation of the literature -- academic, professional, and popular -- for representative information on each of the modifiers of water consumption plus additional topics that have bearing on the modifiers or that can contribute to their improved organization in an integrated form.
2. Interviews with field expert and generalist informants to review development of the end document, with an eye for content, correctness, applicability, and user friendliness. Five interviews are anticipated, primarily focused on research questions 1, 3, and 4.
3. Exploration and reflection of how to best present the information on the range of water consumption modifiers in an integrated format, both within the project document and for other documents that could be derived from this work. The end document is anticipated to contain a series of concise summaries displaying the results of the investigation,

tying together data that is normally only found separately, in particular allowing the comparison of different sources, different conceptions, or different levels within one viewscape. This objective draws on research questions 4 and 5.

Chapter 4: Methodology

Design

Following the mode of ‘desk research’, this project consisted of, from the abundant literature, identifying, evaluating, quantifying, integrating, and presenting in useful form the modifiers of human water consumption. It was quantitative in seeking to meld incomplete, contradictory, and overlapping numerical data and descriptive information into coherent conceptual and numerical frameworks. It was qualitative in seeking to extract -- from the literature and selective interviews of knowledgeable informants -- descriptive information on water consumption characteristics, better understanding of water-related information in the literature, and how the line of inquiry of this project can best provide information to identified end users.

Method/procedure for data gathering

Literature search. For this study relevant water consumption related content was found in all of the following source categories:

1. peer review publications
2. water authority codes, norms, and guidelines
3. water/sanitation related textbooks
4. professional guides
5. project implementation documentation from water-involved entities
6. popular press (for public perceptions related to specific water topics)
7. commercial informational materials (for technology related modifiers)

Literature searches were conducted on both academic databases and general public search engines. Academic materials were accessed primarily through the UAA Consortium Library portal, Google, and Google Scholar. Specific databases used were PubMed, Academic Search Premier, CINAHL (Cumulative Index of Nursing and Allied Health Literature), Water Resources Abstracts, Web of Science, and JSTOR (Journal Storage). For each water consumption modifier or sub-topic, initial exploratory keywords were entered in two or more databases appropriate to the area of inquiry. Abstracts were reviewed and documents chosen for citation, following the criteria listed later in this chapter. Almost all of the literature research was done electronically, though some print texts and grey literature were used, particularly for historical perspective (oldest document reference dated 1956). Documents deemed relevant to the investigation work were placed in one of eighteen digital folders according to modifier and compared with other documents on the same topic. Researcher questions and doubts generated from these readings and comparisons were noted for interviews with field experts or for further electronic investigation. Where applicable, interview information was added to the analysis of each modifier of water consumption. Ultimately, approximately 160 cited sources contributed to the final work.

Interviews. During development of the project chapters, advisory contact was sought with knowledgeable informants on the topics of infrastructure, water consumption, engineering, or the organization of data, to review development of portions of the end document. The interview formats and questions evolved through the research. Initial interview guides were developed relying on personal experience in survey development from psychology coursework, with the expectation that they would evolve. An evolved/consolidated guide can be found in appendix B. The initial idea was that the interviews would add content to the literature-based data. As it became clear that the literature provided ample data and that additional data was less useful than expertise in digesting it, the thrust of the interview component changed to reviewing project components for content coherence, correctness, applicability, and user friendliness. Interviewees were selected from among professional water and sanitation contacts, in particular former Peace Corps colleagues because they were well positioned to provide perspective from both developing nation and high-income nation viewpoints. Each was given by email 1 or 2 modifier chapter drafts and some of the results tables to review, then later (one week minimum) an interview was conducted concentrating on the materials read and ideas each interviewee generated. Input from the interviews was expressed in several ways: clearer expression in certain modifiers, superfluous information removed, and new lines of inquiry developed based on interviewee comments, additional citations based on interviewee recommendations. Though the primary result of the interviews was to improve the research *quality*, where interviewees provided direct research *content*, such is noted in parenthesis as ‘personal communication’, following APA format guidelines.

For the project investigation seven interview requests were made; five interviews were conducted; four of which yielded results usable in the final work.

Criteria for literature investigation and evaluation

Criteria foundations. Sixteen criteria for evaluation of literature findings were developed from the following sources: First, the existing widely-accepted research criteria of *validity*, *reliability*, and *generalizability* formed a general perspective foundation for review of quantitative sources and are reflected in the criteria list of the next section. Second, guidance came from *Standard quality assessment criteria for evaluating primary research papers from a variety of fields* (Kmet, Lee, and Cook, 2004). This broad treatment of assessment criteria provided clear checklists of key issues for assessing quantitative and qualitative work across disciplines. Third, the criteria incorporated consideration of the four qualitative criteria of *credibility*, *transferability*, *dependability*, and *confirmability* proposed by Lincoln and Guba (1985), that are cited and successively expanded upon in Baxter and Eyles (1997) and later in Reid and Gough (2000). Lastly, because this was a health related investigation, materials from the Cochrane Collaboration (2011) and Equator Network (2011) -- two organizations dedicated to fostering and standardizing best practices in the conduct and dissemination of health research -- were reviewed to ensure that the criteria here were not out of line with or overlooking key elements of these standards. While the specific guidelines of the Cochrane Collaboration (and the Equator Network) are more suited to evaluating clinical trials than the investigation approach of this investigation, the Cartesian precision of the Cochrane framework and principles provided useful orientation to the investigation effort. In this research project, application of the criteria attempted to follow four of the five characteristics of systematic review cited in the Cochrane Handbook. These four characteristics are:

-- A clearly stated set of objectives with pre-defined eligibility criteria for studies;

-- An explicit, reproducible methodology;

-- An assessment of the validity of the findings of the included studies;

-- A systematic presentation, and synthesis of the characteristics and findings of the included studies.

The fifth Cochrane Handbook characteristic -- 'a systematic search that attempts to identify all studies that would meet the eligibility criteria' – was not followed in this project, in recognition of the need to place some limits on the scope and depth of inquiry. When looking at clinical trials, it is easy to understand that excluding any relevant studies opens the possibility of confirmation bias or other errors, and reduces statistical power. In this case, the goal of the investigation was not an exhaustive data review -- which would potentially entail review of many thousands of documents -- but rather to simply provide better general contours of understanding and reference points within a very large field of water-related data. It is worth noting that counting just academic papers, the Stockholm International Water Institute and Elsevier (2012) estimated a current production of over 6000 per year under the rubric of 'water resources'.

To provide a credible depth to the investigation in lieu of identification of 'all studies', the following approaches were employed:

-- corroboration of key data from at least two different world class sources, for example, the EPA and WHO

-- estimation of values, where appropriate, using two different methods originating from different sources and assumptions

-- effort to obtain adequate saturation in the investigation to cover the range of the of data in question, if not all of the interior points on that range

-- commitment to avoidance of confirmation bias, by reporting with equal interest conflicting/contradicting data as data which confirms other already found sources

Criteria list. The criteria numbering does not indicate a ranking of importance of criteria. Some flexibility was required in the application of criteria, given the presence of both quantitative and qualitative work, and given the wide range of potentially valid sources, including government documents, agency guidelines, textbooks, manuals, and conference presentations, along with peer review journals.

1. **Relevance**. All studies and data, before being subjected to deeper review, were briefly evaluated for relevance to the central questions.
2. **Size of sample, study, or analysis**. Larger data sets with greater depth and/or breadth were given more priority/attention than those smaller, with allowance made for the tendency of rural studies to include smaller numbers than urban. Where available, meta studies had preference over single point studies (see criterion #16).
3. **Recency**. Where other factors are equal, newer data was selected over old (except where the purpose is to establish trendlines), but older data were not excluded or treated with strong prejudice when it concerns basic water human relationships or water engineering considerations, which are understood to be stable through time.
4. **Generalizability**. Studies and data that lended themselves to universal or broad scales were favored over special cases which may be interesting from a social or

technological innovation standpoint but do not currently have broad application. (The exception in the application of this criterion is the specific section on technological innovation as a potential modifier of consumption).

5. **Freedom from promotional bias**. Data that appeared to proselytize for a technique or technology were discounted or discarded if not corroborated with other independent sources.
6. **Freedom from socio/political bias**. Data that appeared to be biased by express solidarity with a particular sector (e.g. underserved communities), or the reflection of excessive enthusiasm about an approach (e.g. as with conservation education) were discounted or discarded if not corroborated by other independent sources.
7. **Theoretical framework**. Where applicable, studies that explicitly stated and used a theoretical anchoring were favored over those where theoretical underpinnings are implicit or non-existent.
8. **Methodological coherence**. Studies with clearly stated, appropriate methodology that appeared anchored in the scientific method and that justified the approach used were favored over those where assumptions and methods were unstated or suspect.
9. **Documentation adequate to draw independent conclusions**. Studies that provided documentation regarding how results were achieved were favored over those that do not.

10. **Corroboration with other sources**. Data that were well corroborated by multiple sources were favored over data lacking such triangulation. Departures from widely cited data were held to a higher threshold of substantiation before inclusion.
11. **Confounds, mediating or moderating factors, and reverse causality**. Studies that acknowledged other possible explanations for the results found and explored them in a 'non-superficially compliant' way were favored over those that do not.
12. **Contradicting evidence**. Studies that made modest claims, managed the ambiguity of truth well, and confronted and developed contradicting data/views were favored over those that do not.
13. **Number, breadth, and quality of references cited**. Documents that contained more references, of more recent publication, from multiple disciplines, and from peer review journals, were favored over those that had less, or were older, more narrow, or less scholarly. Though not all grey literature shows references, those studies that did were evaluated by the above-mentioned criteria.
14. **Novelty/innovation**. For this investigation, novelty and innovation in methodology or investigation technology was accepted only if the reasoning behind the innovation was fully justified. (This applies to all sections except the 'new technology modifier of consumption').
15. **Publisher**. Though community, city, or provincial data can be highly useful to provide primary data, context, illustration of principles, and nuance, studies or data that were sponsored or disseminated by the internationally recognized

experts of the water/health field (e.g. WHO, PAHO, Sphere, UN, etc.) were favored over data from local sources (e.g. Municipality of Anchorage), except for site specific discussion.

16. **Resolution of data**. Data that was able to support broadly applied decision-making, even if of low resolution, was not prejudiced. Lower resolution data was not specifically preferred, but more exact data that came with a narrow vision or application was of less use for this investigation than less exact data with broader application. The general accounting principle of seeking only ‘the minimum detail and resolution that will support the desired decision-making capability’ reflects this criterion and was applied.

Data analysis

For each modifier a base of data sources and their key points or findings were assembled. As data on the modifiers accumulated through the investigation, multiple rounds of filtering, summarization, combining, and averaging occurred to concentrate the data enough to permit integration into the results chapter, which consists primarily of a collection of tables. Where table display was not efficient or appropriate, succinct narrative ‘summaries of summaries’ were written that allow for reasonable comparison of the modifiers of water consumption in question. Where possible, quantification or approximation of differences in relative importance modifiers and management of uncertainties wass done. A key aspect of making the work accessible to professionals in general and across disciplinary lines was the careful weeding of what was less important to ensure that what was most important did not get choked by too much surrounding material (of which there is a near endless quantity).

Techniques in presentation of results

1. **Mosaic tables** – piecing together incomplete or limited data from differing sources into a larger table than any of the original sources, with a focus on finding congruent fits to make a more coherent whole or a broader picture
2. **Multi-source composite scales** – creating more complete ranges than individual sources usually provide, and averaging multiple sources into single values

Ethics/protections

Most of the data for this investigation were drawn from the public domain and were related to populations as whole entities rather than identifiable individuals. As such the data didn't present manifest problems related to confidentiality or intrusions on personal privacy. However, some issues in initial investigation regarding water in the 'Alaska dimension' chapter (later dropped) were sensitive and rural communities are small enough that frank discussion of water issues may take on a personal flavor. Interviews were conducted following standard consent protocols, including a description of the scope of the interview, its voluntary nature, and its intended purpose. Where any disclosure could result in the perception or the reality of injury to reputation of communities or identifiable groups, the researcher has taken the precaution of reviewing the potentially offending statements with the committee chair or other committee member to gauge their fairness, appropriateness, and usefulness. Where statements have been deemed doubtful on one or more of these three criteria, they have been changed or discarded.

This investigation was under the ethical jurisdiction of the IRB of the University of Alaska Anchorage and was approved with exempt status as of March 13, 2012. Its IRBNet ID is 288869-1. The principal researcher completed the IRB mandated ethical training and refresher coursework prior to initiation of the project. IRB approval was renewed on March 21, 2013, valid for one year. The final IRB report was submitted and accepted on March 20, 2014.

Chapter 5: Finding an initial reference point -- what constitutes water consumption?

Many ways to quantify, many ways to confuse

Lack of clarity about what even is considered ‘consumption’ complicates the discussion of human water consumption numbers under differing circumstances. There are dramatically different ways of quantifying the concept, leading to confusion resulting from apples-to-oranges comparisons in discourse and practical application, as figures unconnected to their differing underlying assumptions are tossed about. (Occasional reference in this section to mainstream or popular sources is not meant to substitute academic citation, but rather to provide insight into the range of what people perceive consumption to be).

To gain a sense of the situation, consider the following: One middle of the road (but not universal) way of tallying human water consumption in a given geographical area is to sum all the residential water delivered, including the water supply distribution losses, and simply divide that figure by the population (e. g. City of Santa Barbara, CA, 2008). Including the distribution losses in this calculation for a modern, well-run, conservation-oriented water system would not fundamentally alter stated figures. In California for example, Santa Barbara’s tightly-managed urban water system distribution losses in 2005 were less than 5% of the total consumption – including or excluding the figure would be of relatively little consequence to macro level understanding or to design decisions. Further, not even knowing whether or not the distribution losses were included in the total would not seriously undermine the worth of the data. However, in the developing world, where leaky water supplies are endemic, the inclusion of distribution losses in calculations could easily distort the real end-user consumption figures. To give a reference-framing estimate, Walker and Velasquez (1999) pegged distribution losses at "close to 50% for all systems where data are available" in a study of water supplies in five developing countries. While some systems have certainly achieved less losses and others could well struggle with even higher losses, the point is that using seemingly equivalent urban water consumption data from the developing world without adequate detail behind the figures could easily lead an observer to draw erroneous conclusions about real use and needs in developing world settings. Given the magnitude of possible error, the observer could easily conclude that developing world water users actually consume more than those from rich countries.

In making water consumption statements, some may include or subtract distribution losses for their figures, or make no mention of the issue (e. g. Cornerstones Municipal Utility District, 2001), resulting in figures that undermine accurate comparison (Aquaterra, 2008). Moreover, all of the preceding analysis is within just a single construct of water consumption. Others use an entirely different approach to define the term -- an ecological or footprint measure for calculating water consumption. This includes indirect uses such as the water required for food production and manufactured consumer goods (e.g. WFN, 2012; USGS, 2011; Postel et al, 1996) in addition to the water we see at the dispensing point. This in the United States amounts to 4000 liters or more per capita per day -- a completely different class of figure than the approximately 120 to 600 liter per capita figures that can be found for direct residential domestic consumption in a modern urban setting (detail and citations provided in subsequent chapters). Discrepancies of this magnitude can thoroughly confuse any non-expert and many expert users of water data in a way analogous to how the ‘2% milk confound’ operates and perpetuates in the public sphere: While fat content of “reduced fat milk” is *by volume* 2%, the fat content of the same milk by *proportion of total calories* is closer to 20% (milk carton, 2011). The former measure is the dairy industry method for calculating and labeling fat (using the water in milk as part of the calculation denominator); the latter measure, separated by a full order of magnitude, is the calculation method favored by nutritionists and shows up on the reverse panel of the same container. The use of both numbers semi-interchangeably in the public arena, and understandably not always with tedious reference to the method of calculation nor its meaning, provides an object lesson in how even completely accurate data can foster continual confusion about what is reality. In the water realm, an analogous example (among many that exist) of the situation can be found on an informative-looking page headlined “We use how much water? Scary water footprints country by country” (Streeter, 2009). There, footprint data were blithely mixed with residential direct use data as if they were the same thing simply by virtue of being about the same thing – water.

A recent FAO (United Nations Food and Agriculture Organization) report entitled *Disambiguation of water use statistics* (Kolhi, Frenken, & Spottorno, 2010) was explicit about this issue as an ongoing problem in the sector. Quoting from its introduction,

> Water statistics at all levels are crucial for sustainable development and management. They shape policy, decision-making, and act as a proxy for development . . . . Unfortunately the nomenclature surrounding water

> information is often confusing and gives rise to different interpretations and thus confusion. When discussing the way in which renewable water resources are used, the terms water use, withdrawal, consumption, abstraction, extraction, utilization, supply, and demand are often used without clearly stating what is meant.

The FAO report made an effort to shine a light on the issue, yet to say that any meaningful unity on terminology has emerged would be optimistic. In a review of the diverse minimum water requirements used for social and economic development, Chenoweth (2008) reinforced the concern articulated in the FAO report. He found and decried that such standards for human water consumption from differing sources can range between 20 and 4,654 lpcd [Chenoweth figures], undermining the establishment of meaningful parameters of acceptability and goals for human water consumption.

While the focus of this investigation was not specifically the disambiguation of the term water consumption itself, any inquiry into and evaluation of the modifiers of water consumption requires disambiguation as foundational to the effort.

Three dimensions of water consumption

Looking over the range of available sources, academic, professional, and popular, the following three groupings of water consumption designations could be cautiously made:

- **the water footprint**, covering a broad ecologic view of our consumption of water, and measured in *hundreds to thousands of liters* per capita per day (3 to 4 digits);

- **individual direct water use**, or domestic water, covering essentially water that comes from sources over which we exercise the ability to open or close the flow, centered in the household environment, and measured from the *tens to hundreds of liters* per capita per day (2 to 3 digits); and
- **water ingestion**, which covers the our literal consumption by taking water into our bodies, mostly through drinking, and measured in *single digit liters* per capita per day (1 digit)

Surprisingly, attaching a single good label to any of the categories is not easy. For example, even seemingly such obvious delineation as water you drink being called 'drinking water' cannot be trusted to provide the desired clarity. The following page (Figure 5-1) is nothing unusual.

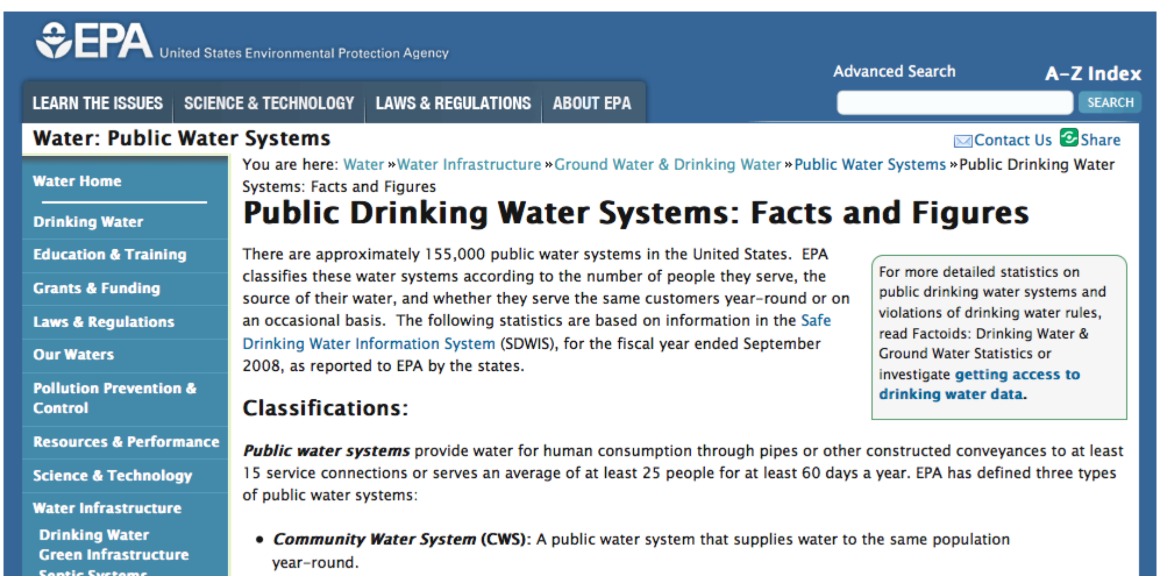


Figure 5-1. Drinking water that actually means domestic water. (Fragment)

(EPA, 2012).

In its public information material, the EPA (Environmental Protection Agency) makes frequent reference to drinking water, but it is to mean all the water used in a residential or domestic setting, including water flushed down a toilet. It's not that the EPA is wrong to do so – the usage is widespread and likely anchored in current regulations stipulating that all residential water be drinkable – it simply means that to distinguish something as simple as *drinking water* as commonly understood from *drinking water* as might be literally defined, care is required. All three conceptualizations expropriate the term 'water consumption' in one situation or another. With clear definition and differentiation of these terms an essential precondition of exploring water use in the infrastructure setting, a description, approximate quantification, and proposed labeling of each is provided in the following sections.

Water footprint

AKA: water withdrawal, ecological water, extraction, abstraction, utilization, water consumption, virtual water, managed water

The water footprint is an extraordinarily useful concept for grasping the full impact of our life choices on water consumption, as well as the immense leverage we have in change potential within those choices. An ecological measure, the number derives from the total withdrawal of fresh water required to support the full radius of our actions including the creation/consumption of food and other products.

There are numerous ways of breaking down the water footprint. Two introductory examples are given in Figure 5-2. In both examples the blue corresponds to the agriculture portion of the footprint; in the left-hand chart much of the yellow slice – water for energy – could also be identified as part of the blue (energy inputs into the food production process). In each, domestic consumption is found within the thin red slice.

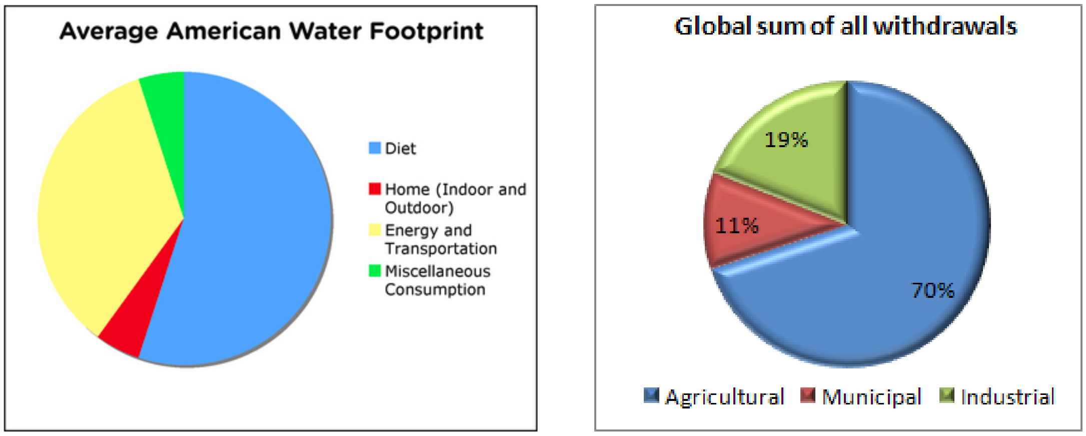


Figure 5-2. Examples of different water footprint views and category breakdowns.

1. Postel (2010); 2. FAO AQUASTAT (2005)

An immediate and compelling fact emerges from looking at water footprint figures: Our individual, direct water consumption is only a small fraction of our total ecological or footprint use. This is generally true for both low-income and high-income nations (see direct and footprint comparison values in Table 17-B). Postel (2010) attributed just 5% of the U.S. footprint to domestic water use. By all footprint measures, water input into our food (i.e. via agriculture) is far and away the largest component of the water footprint, accounting by some respected calculation methods for more than 90% of the total (e.g. Hoekstra & Mekonnen, 2011), and in no case less than 70% (FAO AQUASTAT, 2005). Footprint water data is useful for broad understanding but is potentially an element of confusion in application to infrastructure design or personal use parameters in a residential/domestic context, particularly if not at least conceptually differentiated.

A prominent sample of the ecological perspective and its ability to turn ‘tangible water based’ thinking on its head was provided by the Water Footprint Network (2012): hidden inside a single liter of milk are found 880 liters of water by the footprint method, that which was used to create the milk. Though the water use is real, at the level of the milk drinker this is a distant abstraction. As we either know or can well imagine if we stop to do so, vegetables, fruits, grains, cars, computers, concrete blocks, furniture, clothing, most everything we eat or use, has an invisible and sometimes counterintuitive water use component ‘embedded’ in its creation: the water footprint calculated from both the visible and invisible consumption. The term virtual water is often applied to invisible, embedded water, and because virtual water can constitute most of the footprint, footprint and virtual water are terms sometimes used interchangeably (e.g. Dourte & Friasse, 2012). Hierarchically speaking however, virtual water (invisible) should be considered a subset of the water footprint (both visible and invisible).

Red meat requires special mention when discussing water footprints. Per capita average beef consumption in the U.S. is at about .07 kilos per day (USDA, 2003). By a footprint reckoning each kilo of beef produced requires 15,400 liters of water (Mekonnen & Hokekstra, 2010), thus approximately 1000 liters in daily per capita water consumption can be attributed to that single item just by following an average American diet. This is a far larger amount than what we use in direct consumption. Conforming to USDA dietary guidelines for meat would only slightly lower the number (Wells & Buzby, 2008).

Determining water footprint values requires a number of arbitrary scope and analysis decisions and there is some debate over certain aspects of quantification of this concept, which contributes to a range of values being found in the literature (e.g. Hoekstra, Chapagain, Aldaya, & Mekonnen, 2011; Kolhi, Frenken, & Spottorno, 2010). For example, large quantities of water may be used for cooling in manufacturing processes of a particular good or in power generation (e.g. Fry, 2005). The water is in some cases returned to its source unaltered except for heat absorbed and/or the fact of being returned at a somewhat lower altitude (admittedly, neither are considered trivial changes from an environmental perspective). There is not yet a consensus on whether or how this class of use should be considered and quantified in calculating a water footprint. Other confounds are: water-for-recreation amounts, food and other products that are exported or imported, water confined temporarily by dams for power production (also subject to evaporation losses), and water removed from sources for irrigation but returned as runoff. Hoekstra, Chapagain, Aldaya, and Mekonnen (2011) discussed multiple methodological challenges in footprint calculation, including where to "truncate the analysis" of what is in reality a continuous cycle, and how to evaluate separately – then re-integrate surface water use, water use drawn from aquifers, and water polluted though human use.

The comprehensive *Water footprint assessment manual* of Hoekstra, Chapagain, Aldaya, and Mekonnen (2011) may emerge as a gold standard for footprint calculation. It is institutionally linked to the Water Footprint Network. The Hoekstra et al. approach is notable for its differentiation between "fossil" water (relatively permanent underground water of long-time accumulation in aquifers) and "renewable" water (in the form of precipitation cycles). They also build the volume of water polluted into their footprint equation, resulting in three categories within the water footprint: green water for rain, blue water for groundwater, and grey water for polluted water.

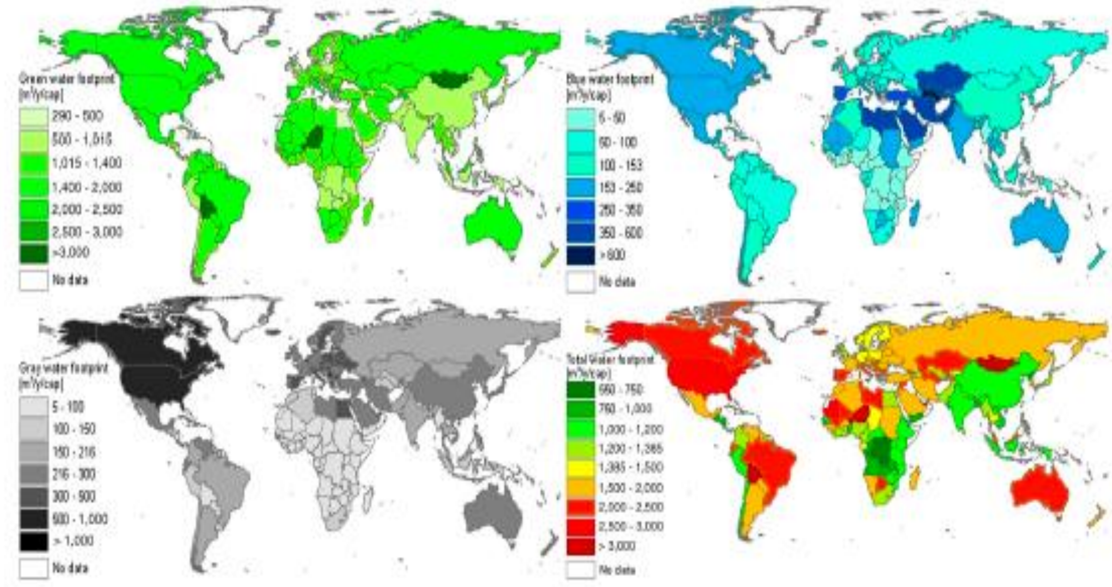


Figure 5-3. Comparative green, blue, grey, total water footprints by country (m³pcy)

Hokestra and Mekonnen, 2011

Also notable in the Hoekstra, Chapagain, Aldaya, and Mekonnen approach is an accountant mindset and a differentiated analysis framework depending on whether the scope of inquiry is a process, product, consumer, community, watershed, business, nation, or humanity as a whole.

The AQUASTAT approach is somewhat easier to grasp and is institutionally linked to the FAO, giving it a high degree of exposure. However, it does not provide water source breakdowns for multidimensional understanding of water use.

AQUASTAT sectors	Water use category	Self-supplied / Network
Agricultural water withdrawal	Irrigation	Self-supplied
	Livestock	
	Aquaculture	
Municipal water withdrawal	Domestic	Network
	Irrigation	
	Livestock	
	Industrial	
	Thermoelectric	
	Mining	
	Commercial	
Municipal water withdrawal if explicitly stated, else agricultural water withdrawal	Domestic	Self-supplied
	Commercial	
Industrial water withdrawal	Industrial	Self-supplied
	Thermoelectric	
	Mining	
NOT counted	Hydroelectric	
	Recreation	
	Freshwater capture fisheries	
	Navigation	

Figure 5-4. A snapshot of the AQUASTAT components of water footprint.

(FAO, 2010).

Disparities between methodologies are substantial, and regardless of how the water footprint is measured, disparities between countries and between continents are also substantial. Figure 5-5, though somewhat dated and expressed in cubic-meters-per-year rather than liters-per-day (1 m^3py = 2.74 lpcd), is useful to illustrate at a glance the spread in relative consumption levels across continents and economic ideologies. In this figure, the widest spread is between North America and Africa, with a greater than seven-fold difference (expressed in liters-per-capita-per-day the range is 671 to 5099). These numbers fit within the fan of current footprint estimates. Note that the use of older citations for water use should not be considered a serious flaw, given that the countervailing forces of growing affluence vs. increased efficiency in water use appear to hold the basic data around the water consumption relatively stable or in gentle decline (e.g. Rockaway, 2011).

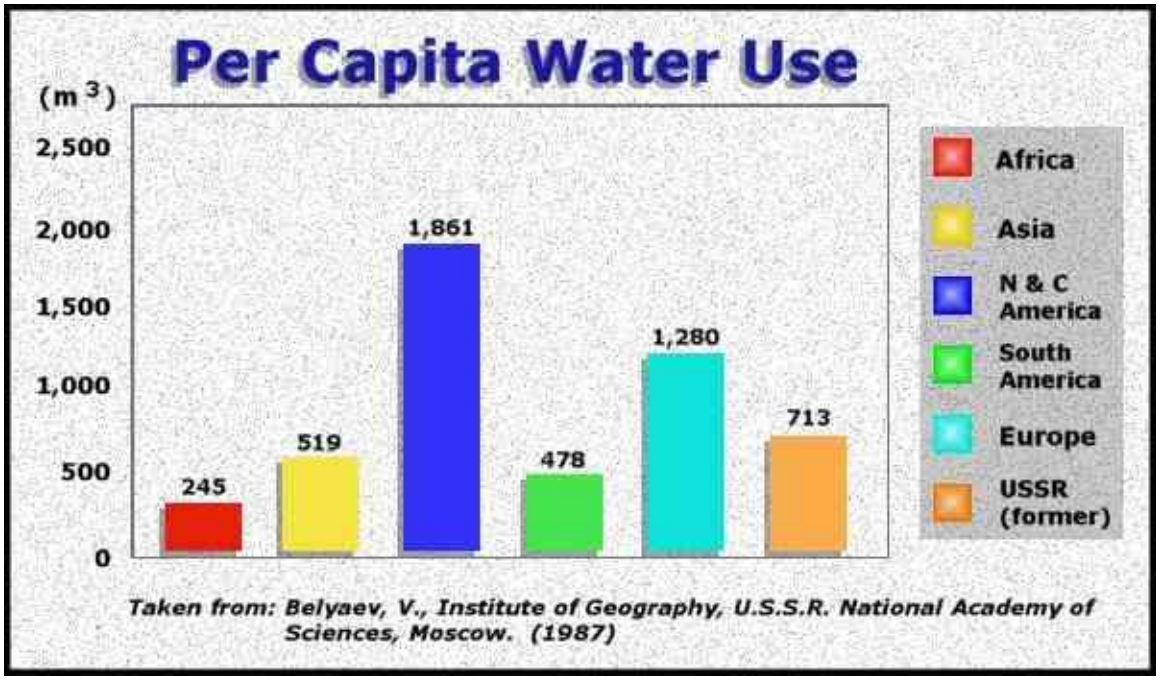


Figure 5-5. A per capita water footprint comparison between world regions.

(in Global Change, 2000)

Variation in data resulting from differing calculation methodologies appears to be less than water use differences within a given methodology, but not by much. Following is a chart of key country footprints by Hoekstra and Chapagain (2008) showing a somewhat higher range than the previous figure (Figure 5-6). Note also in this chart the agricultural, industrial, and domestic water breakdowns are seen in each column, with agriculture (in black) dominant always, though in differing degrees.

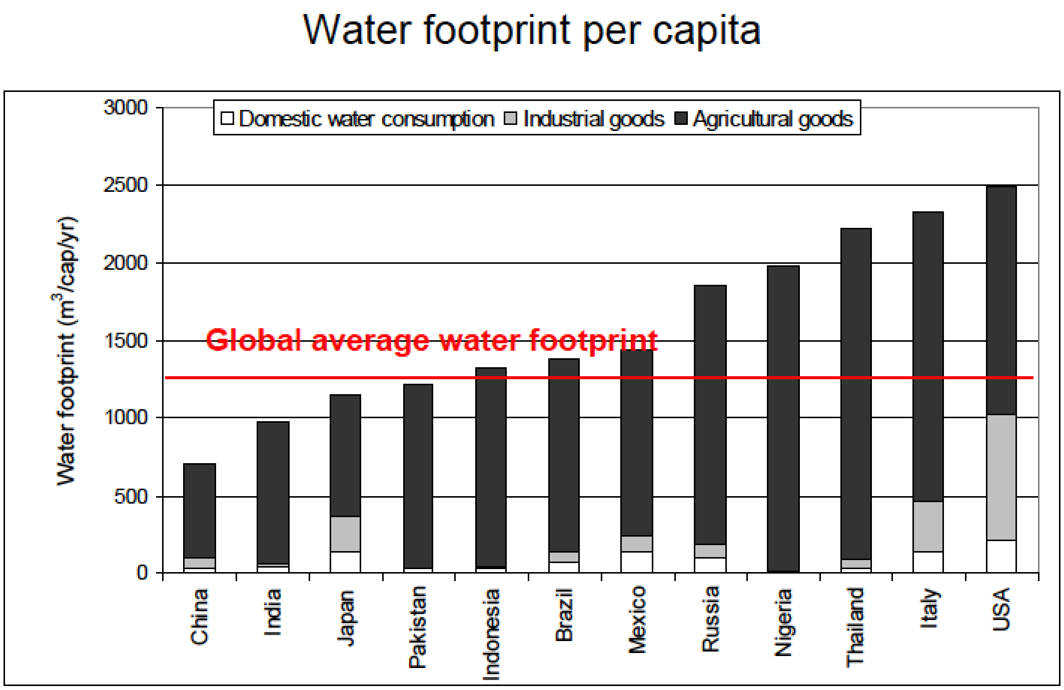


Figure 5-6. Selected country water footprints (USA 6,800 lpcd; China 2000 lpcd) (Hokestra & Chapagain, 2008)

Water use levels in African and Asian nations are generally among the world's lowest, though it is not entirely safe to generalize. According to Hoekstra and Mekonnen, (2011), Niger, Mongolia, and Bolivia -- all desperately poor and on three different continents -- happen to occupy the three top spots in the world for per capita water consumption. This is likely because of extraordinarily inefficient infrastructure or large groundwater withdrawals. They're followed immediately by the United States. This datum highlights the bi-modal nature of egregious consumption. The high consumption levels of the most affluent nations resulting from wealth, power, and control of resources can be matched occasionally by high use among the poorest, due to the inability to afford water-saving technology or basic water-accountability technology, i.e. water meters.

Numbers cited under the footprint water use concept run from a low just under 700 lpcd (Global Change, 2006) to a high over 10,000 lpcd (Hoekstra & Mekonnen, 2011). The world averages within these sources and others congregate at around 3000 or 4000 lpcd, which can serve as an anchoring/calibrating reference. For the purpose of this investigation, the data resolution needed is only that which will allow the reader to have a macro-level sense of the meaning of footprint consumption and to distinguish water footprint consumption from direct household/residential/domestic consumption when numbers are tossed about without context. It is a reasonable assumption that when someone states that the average person uses X thousand liters of water per day, whether it's one thousand or ten thousand, they are likely referring to footprint consumption rather than domestic. This illustrates a key reason for a general understanding of the different categories: it permits the listener to know from just the range of figures discussed what is the category of reference, even when the speaker of these numbers is unaware.

Domestic water consumption

AKA: drinking water, residential water, household water, potable water, water consumption

This measure encompasses the water under our direct management and visible to us, usually within the domestic/residential sphere. It may be dispensed by an urban water distribution scheme into homes, or be drawn from a well or public tap. According to World Health Organization data (2012), for approximately 800 million persons around the world, domestic water continues to be an unimproved source (i.e. an unprotected body, flow, or access point of water; or a water source greater than 1000 meters distant from the point of use).

Though we are all biologically similar in our water need, the domestic consumption numbers range from as little as 7 lpcd to over 600 lpcd (extensive citations following), depending on a multitude of factors that are examined in the following chapters of this investigation – the modifiers. It is worth noting that a range from 7 to 600 is greater than a 80-fold difference for what is a universal and essential human health need, and as such, constitutes a working definition of disparity.

If viewed from a worldwide perspective, domestic water follows a bimodal distribution, with two fundamentally different realities resulting in two essentially discontinuous ranges. The most prominent feature of the divide is the use of dry sanitation versus flush toilets for human waste removal, even though the difference is greater than simply the water physically used or not used by the toilet.

For OECD nations, consumption is generally above 120 lpcd and, depending on the country in question, the sources used, and the methodology of measurement, can crest at 600 lpcd. For the poorest developing nations, the numbers are well below 50 lpcd (see Figure 5-7).

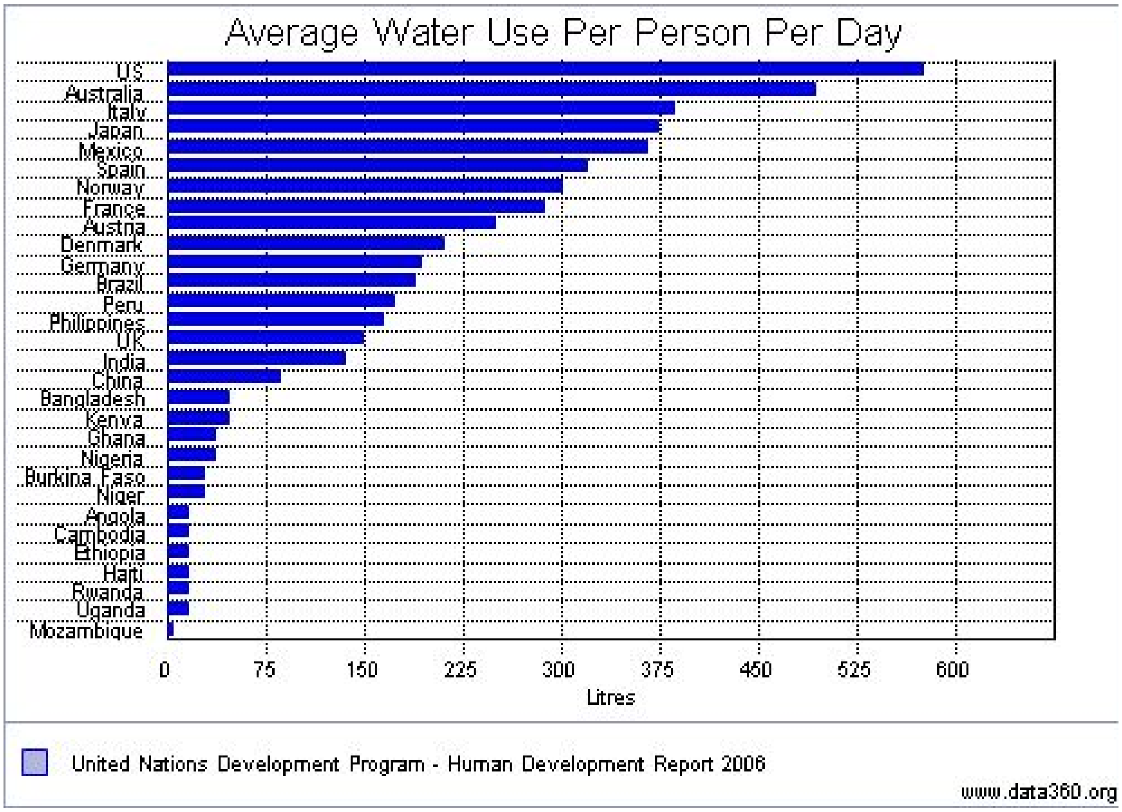


Figure 5-7. Domestic water consumption, selected countries

UNDP (2006)

While there is room for debate over the UNDP numbers in Figure 5-7, the general contours are supported by other sources. The USGS (2013), for example, pegged U.S. per capita domestic consumption somewhat lower, at 80-100 gallons per day (303 to 378 liters), falling between Norway and Japan on the UNDP chart. The REUWS (1999) put the U.S. total a bit higher, at 650 lpcd. In all cases, it is an order of magnitude more than the bottom five selected countries on the UNDP list, all developing countries at 25 lpcd or below.

The domestic definition of water consumption is the standard used for the water component of the U. N. Millennium Development Goals. This standard includes water for cooking, hand washing, bathing, laundering, cleaning, domestic watering, and in some cases -- human waste carriage. Water ingested is only a small portion of the total (reviewed next). In turn, total domestic water consumption is only a small component of the water footprint. The domestic use category is the primary one relevant for potable water system infrastructure, human habitat design issues, and direct personal control over use at the tap.

Further exploration of this category is the focus of chapters 8 to 17 of this thesis.

Water ingestion

AKA: water consumption, drinking water, water intake

Occasionally what is meant by the term water consumption is truly the water we take into our bodies, consumed in the literal sense. This number can vary depending on personal preference, ambient heat, and work performed, from as little as one liter per day to approximately seven liters per day for athletes in training or those carrying out intense physical labor in hot climates. Widely quoted recommendations center around three liters (e.g. USDA, Easycalculation). The following range citing six sources is found in Gleick:

Source	Average daily water intake in liters per capita per day
Vinograd [8]; Roth [9]	2.5[b]
World Health Organization [10]	2.5
White et al. [4]	1.8 to 3.0
U.S. Environmental Protection Agency [11]	2.0
National Academy of Sciences [12]	2.0
Saunders and Warford [13]	5

[a] During normal activity and temperate climate.
[b] This value represents the actual fluid requirements measured for early space flights. The recommended intake minimum for Apollo astronauts under routine conditions in the command module was 2.9 liters per day.

Figure 5-8. A range of water ingestion requirements.

Gleick (1996)

Howard and Bartram (2003) place gender, child/adult status, workload, temperature, and pregnancy status in a matrix, providing a summary with a range of 1 to 5.5 liters:

	Volumes (litres/day)		
	Average conditions	Manual labour in high temperatures	Total needs in pregnancy/lactation
Female adults	2.2	4.5	4.8 (pregnancy) 5.5 (lactation)
Male adults	2.9	4.5	-
Children	1.0	4.5	-

Figure 5-9. Water intake as varies by gender, age, work load, and temperature

Howard and Bartram (2003)

Like the other categories, this category is a legitimate interpretation of the term ‘water consumption’ and more importantly, it is confusable with the bottom of category 2 listed previously. Indeed, the term ‘human survival water needs’ can refer to many levels of consumption: the above mentioned minimum physical intake requirement of around two or three liters . . . the anticipated household consumption level of seven liters (when the supply is severely restricted or when the user must travel a kilometer or more to the water source and carry it back) . . . the fifteen liters deemed the minimum amount necessary by the World Health Organization and the Sphere Project in refugee situations (2004, 2011) . . . or, finally, the widely used minimum of fifty liters to maintain “a persons water balance and provide benefits vital for human health” (Gleick, 1996). A check with a refugee camp engineer (Andrea Stancliff, personal communication, 30 Jan 2013) indicated common use of the SPHERE/WHO 15 lpcd level as a recognized standard minimum acceptable level for basic survival in humanitarian emergency situations and refugee camps.

Water consumption at the level of physical intake is discussed in a framework of individual health and nutrition generally, with some attention as a medical issue when insufficient or excess quantities are ingested. Water, though an essential substance for life, is peculiar in that its ‘therapeutic dose’ range is unusually narrow. Water toxicity can actually occur with as few as four liters if consumed rapidly enough. Deaths have occurred at six to seven liters (e.g. Clarke & McHugh, 2009), a number notable for actually being within the range of normal daily consumption. If one liter is accepted as a healthy dose at one time, the therapeutic ratio is then approximately 6:1, far below that of alcohol or most other substances that humans generally consume. Excess water consumption is referred to clinically as hyponatremia, a state of electrolyte imbalance. Cases are rare but not unheard of, linked to schizophrenia in some instances, or a psychological disorder involving a pronounced desire to take in large quantities of liquid, termed polydipsia (e.g. Loas & Mercier-Guidez, 2002 and Peh, Devan, & Eu, 1990). Certain drug use (e.g. MDMA), demanding and dehydrating sports activities (e.g. marathons), or incidents of hazing and other settings of forced rapid water ingestion (fraternity initiations, contests) are also causing agents (e.g. Clarke & McHugh). These facets are briefly mentioned here because the term ‘water consumption’, if misunderstood, can actually be mistaken for these intake ‘dosage levels’. At the other end of the spectrum, shortfalls in water ingestion can result in death after a few days (e.g. Water Policy Int’l, 2012), making it second only to air in terms of substances essential to human survival.

Ranges of use summarized

The following table displays in a single page view a summary of the three categories of the term water consumption and frames the concepts applied to it. Though the bulk of this investigation is built around the middle category, doubts about the relevance of domestic water can emerge that demand response when the numbers of the three categories are viewed together.

Table 5-A. Understanding what people mean when they say 'water consumption'

Consumption construct	Range of use lpcd	Approx. middle value lpcd	Relevant use	Notes
Water footprint **Also withdrawal, extraction, abstraction, consumption, water footprint, virtual water plus direct use water**	~700 to 10,000	3500	Ecologic study; understanding of impact of consumer decisions	>80% result of agricultural activity
Individual direct water use **Also consumption, residential use, direct use, potable water, domestic water, drinking water**	7 to 600	50 dev world 200 OECD nations	Human habitat design; understanding of domestic water use	Bimodal distribution Confounded by dry vs flush sanitation component and other modifiers
Water ingestion **Also consumption, drinking requirements, water intake**	2 to 7	3	Medical, nutrition, emergency and disaster situations	Confounded by water in food. Water essential to life but toxic at doses >6 liters

Footprint vs. domestic consumption for decisions and action

When the water consumption data is presented in this way, covering the spectrum of the concept, it appears that the most 'numerically dramatic' control over any modification of water consumption lies within our food choices, rather than by modification of our direct water consumption. This leads to the following legitimate question: why be concerned about conserving water at the residential/domestic/household direct use level if it is at the footprint level where 90% of the total consumption occurs? The math is stark. Just a 10% reduction in the 90% component would be of the same net consequence as, and presumably far easier to achieve than, a 90% reduction in the 10% component (i.e. 0.10 x 0.90 = 0.90 x 0.10).

Response to this question requires examination of the location of water consumption rather just the amount consumed, as well as the quality of water for different categories of consumption. For per capita footprint consumption, a large portion of the water can be ‘consumed’ far away from the end beneficiary to whom the consumption is attributed. Thus footprint water inputs can accrue in places where water is abundant, while the ‘distilled’ good that is created in part with the water can be consumed anywhere. This is the essence of the virtual water concept. On the other hand, residential/household water consumption requires that the specific substance of water -- usually of the highest quality -- be delivered to the house or the family compound, or at least close to it. Fair comparison across the categories and prospects for substitution could only be done with differentiated valuation that takes into account the quality or purity, and the location of delivery or use along with the quantity; this would entail complicated metrics. Hokestra and others have pursued work in this direction. For the purpose of the investigation it’s sufficient to affirm conceptually that in recognition of qualitative differences the liters cited in the different categories are not entirely interchangeable, and at the same time acknowledge that there is some amount of feasible transfer from one to another. Cities can and do expand their residential water supplies routinely through acquisition of rural agriculture water sources or rights (e.g. Reisner, 1986). The fact that some of our residential/household water can be drawn from the current reservoir of footprint water justifies the idea that it is appropriate to look at footprint water more closely when considering issues of domestic water, particularly if the focus is consumption, conservation, or scarcity.

Conclusions/actions

-There is widespread disagreement over what constitutes water consumption, undermining research, understanding, clear communication, and the setting of standards.

-It is possible to distinguish three broad water consumption categories (footprint, domestic, ingestion), characterized by overlapping definitions and with wide disparity both within and between the categories.

-A middle road reference human water footprint value is 3500 lpcd; a domestic water value could be 300 lpcd for industrialized, preponderantly urban settings, and 50 lpcd for developing nation rural settings; an ingestion reference value is about 3 lpcd.

-Footprint water use, driven primarily by agriculture, is a full order of magnitude larger than domestic water use. The sheer size of footprint water and the fact that footprint water is a potential source for domestic water justify looking at footprint water in the context of domestic water needs.

-Though footprint water does not always directly connect to or affect domestic use, to be involved in domestic water issues requires sufficient understanding of the water footprint to avoid risk of being blindsided in discussion or analysis by the footprint perspective and data.

Chapter 6: The water footprint and water scarcity

Water footprint and domestic water investigation

Given the outsized and often unacknowledged influence of the water footprint within the realm of water consumption overall, and because potential domestic water resources can at least to some degree be drawn from the footprint, issues related to footprint water abundance, scarcity, or disparity warrant an examination alongside the domestic water modifiers of consumption. In particular, some demand-side savings identifiable in the footprint hold the possibility to provide new water resources or count as security buffers against shortage.

A critical look at water scarcity

The notion of an impending water scarcity crisis is a staple of water issues discussion and relentlessly alluded to in both popular and learned press. It is a powerful driver of the dialogue of water conservation. Figure 6-1 is emblematic of a typical portrayal of future water prospects, complete with arresting images designed to put the viewer in a state of unease.

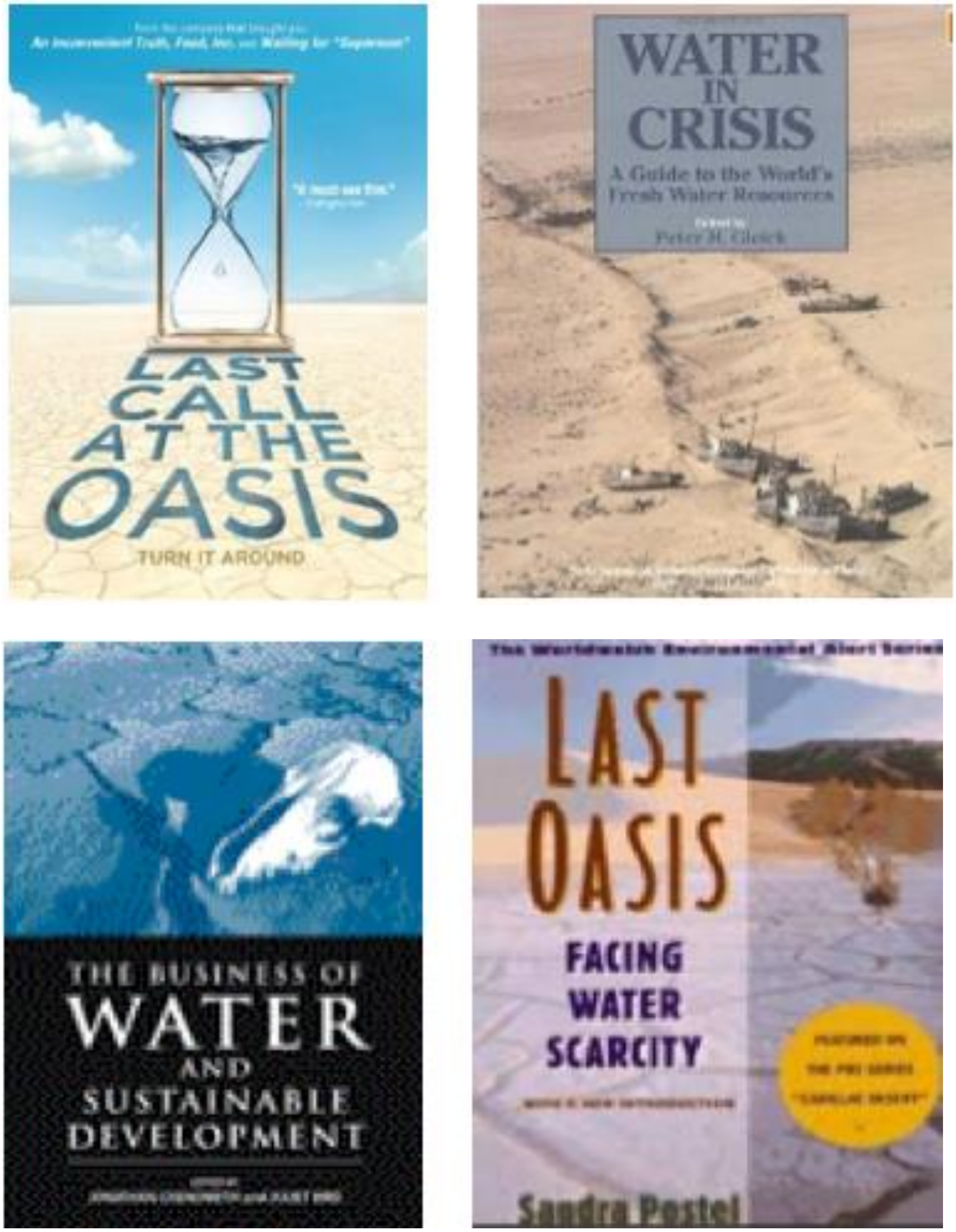


Figure 6-1. Images portraying specter of water scarcity

1. Yu, 2. Gleick, 3. Chenoweth and Bird, ed., 4. Postel

However, the water footprint data appear to support a hypothesis that the water-scarcity-crisis perspective, which is used to justify our attention to water consumption, is a fallacy. We are not necessarily facing a total water shortfall of Malthusian proportions, as is sometimes reported, if we are willing to acknowledge the following three points:

1) the food-driven portion of the water footprint (i.e. agriculture) is where the preponderance of the total human water consumption lies,

2) different foodstuffs have very different water footprints (water intensity) per calorie of energy and nutrient delivered, and

3) there is substantial elasticity in our food choices, particularly as regards meat consumption, total caloric intake, and food waste.

Finding a credible meat-grain-water linkage

To make a foundation for the hypothesis that we are not necessarily facing imminent shortfall, it is necessary to numerically link the variation in water intensity of our food sources to the inefficiency in the conversion ratio of caloric input to output involved in the creation of meat. Meat is largely a derivative of grain, a foodstuff in its own right. Widely circulated and cited estimates of the grain-to-meat ratio run from a low of 3:1 to as high as 20:1 (i.e. up to 20 edible cereal calories are needed to produce one calorie of red meat, e.g. Roberts, 2008). The claims of 20:1 conversion ratios may well be unrealistically high and are sometimes put forward by persons or entities that have a detectable bias against the consumption of meat for pragmatic, moral, or political reasons (e.g. Lappe, 2009; Rifkin, 2007). However, calculations made in this project investigation (see appendix F), using U.S. Cooperative Extension Service (2008) data did support at least a 6:1 ratio for beef. Poultry and pork, the other most often consumed meats, could be somewhat lower. With approximately 20% of dietary calories currently coming from meat in an American diet (e.g. Wells & Buzby, 2008; see also appendix E calculations), a caloric reserve greater than the *entire current food consumption requirement* of the U.S. is potentially latent within our existing meat consumption. Using the ratio of 6 grain-based calories to produce 1 meat-based calorie means that the caloric value of the grain used in current meat production is in the neighborhood of 120% of our total caloric needs (20% x 6). This information is sometimes expressed for dramatic effect from another angle: most of all oats and corn in the U.S. are grown *not* to feed humans, but rather the farm animals that are then slaughtered to feed humans (e.g. Dick, undated; USDA, 2012). Until around 2005, reference in the press indicated numbers in the range of 80% of available corn going to feed rather than food. More recently part of the corn crop has been diverted to ethanol production. The ethanol diversion of grain does not weaken the argument: the percentage of grown corn used for food remains small. Note the narrow red band in Figure 6-2 below, corresponding to food primarily, and which remains nearly constant between 1981 and 2013, even as grain for fuel expands as a category.

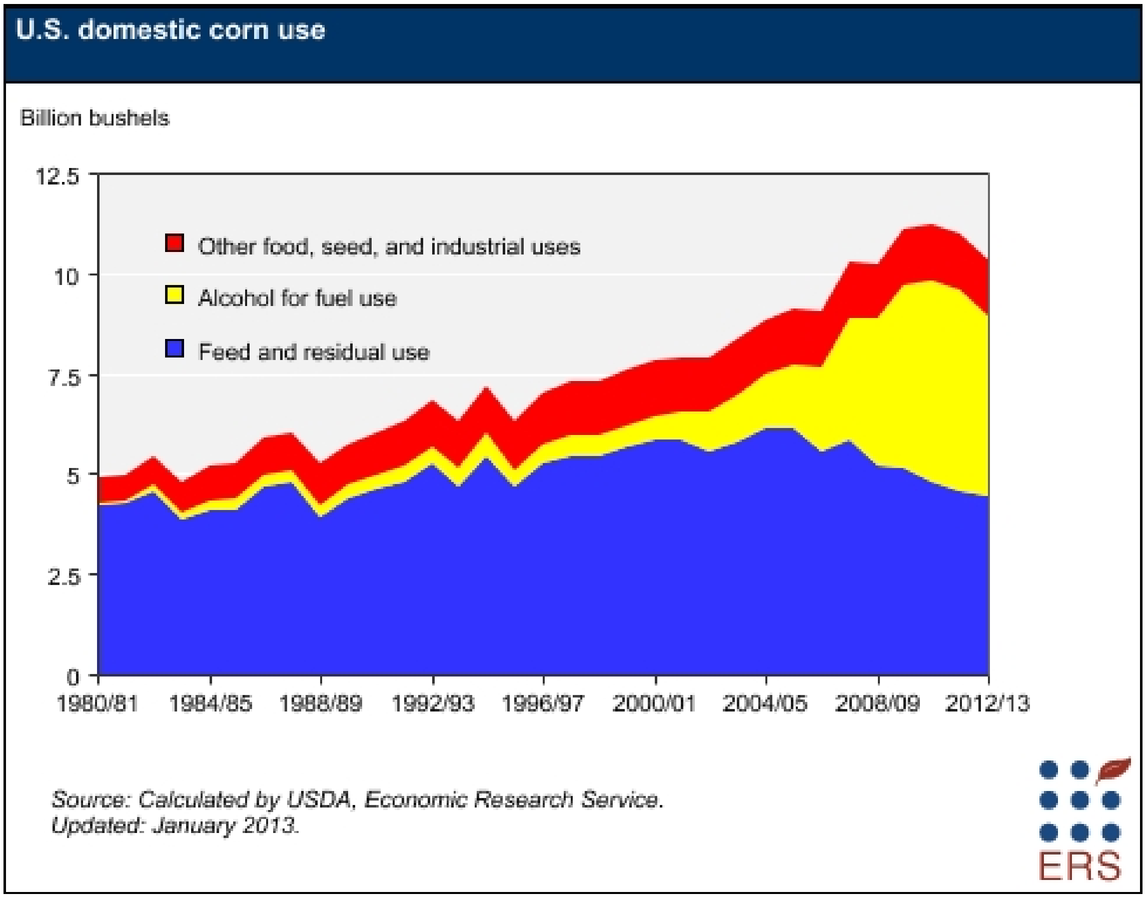


Figure 6-2. U.S. corn use for feed (blue), fuel (yellow), and food (red)

USDA Economic Research Service (2013)

While the information that most of our grown grain is not even directly for us to eat is attention-getting, it doesn't expose the more relevant understanding, planning, and decision-making fact that the edible grain inputs that are 'passed through an animal' or put into an engine could alone supply and surpass the total current caloric needs of the country. (This discussion does not parse 'grain vs. meat' protein content and nutritional values, but both grains and meat are recognized as able to supply adequate diet protein and a useful range of nutrients. Meat protein may be more valuable economically than grain protein, but it is not necessarily healthier, and in meat-rich diets a portion of the meat protein may in any case be metabolized as less valuable carbohydrate. Detailed comparison is beyond the scope of the investigation).

The point of discussing the grain-to-meat ratio for this investigation is not to promote a vegetarian diet nor directly address food issues, but rather to trace a line from meat consumption to the vast amount of currently grown non-human grain consumption and in turn to a vast water footprint. The physiological ability of humans to consume less meat if circumstances required it, or if it were determined to be desirable for improved health, constitutes (from demand-management, long-range planning, and disaster-preparedness perspectives) an enormous untapped and uncalculated reserve of scalable, cost-reducing, and positive-health-impact water savings readily available to us.

This complete line of thought does not appear to be well represented in the literature, though portions of it are. Frank Rijsberman, head of the water, sanitation, and hygiene program at the Bill and Melinda Gates Foundation, circulated in 2011 an article entitled *One Liter = One Calorie* in which he tied food production to water use at the level of one to one. The one liter to one calorie equality was unsupported, but data posted by the Water Footprint Network (2012) roughly bear him out: the aggregate of foodstuffs around the world have in the vicinity of a liter of water embedded in an average calorie. Red meat, because of its grazing and grain inputs, has several times that amount (conservatively, six, as discussed earlier). Though his conclusions follow conventional thinking in terms of the perspective: ‘we are running out of water because we need food and will soon will need more food and more water to grow it’ and he does not provide analysis of the water intensity difference between one food and another, the use of the liter-to-calorie construct does constitute a corroborating example of linking food to available water.

Late in the development of this research, Vanham, Mekonnen, and Hoekstra (2013) published an article that does make practical and numerical connections between diet alternatives and water consumption. Their frame of reference was large scale (pan-European), the topic extensively researched (+40 references), and the authors offered specific liters-of-water quantification of different actual diets and proposed diets.

Vanham et al. examined and compiled an average diet across the European Union (EU 28), tracking both calories and diet makeup. They then put together three other alternative diet scenarios: one based on the recommendations of the German Nutrition Society, then a vegetarian diet, and finally a ‘middle road’ diet that takes a position between the vegetarian diet and the Germany Nutrition Society diet. The authors found 1610 lpcd of water available for recapture in shifting from the average diet to a vegetarian diet, and more realistically, simply adopting the German Nutrition Society diet still yielded 974 lpcd of water saving. Against the backdrop of data from multiple sources (e.g. Aquaterra, 2008; Vanham et al.) showing European total *domestic* consumption at relatively small values, (between 120 and 150 lpcd), the potential diet based *footprint* water savings numbers are too large to ignore.

The approach of Vanham et al. was different than that used in this investigation but their data point in the same direction and come to similar numbers as the calculations of the following sections of this chapter.

It should be acknowledged that many others have highlighted the fact that our food intake creates a large water footprint, but this information is usually presented in the narrow context of a problem ("we consume too much") with the exhortation to consume less, rather than a more pragmatic view of potentially mining footprint water as tapable resource and meriting discussion of actual liters freed up through dietary modifications.

Determining specific available recapture water in diet

Available water in meat. From a viewpoint of macro level water-understanding, establishing some reference-providing numbers regarding the magnitude of the water consumption savings linked to excess (or counterproductive) calories would be useful for reframing our understanding of footprint water. I believe there are at least three areas of identifiable and quantifiable savings available for recapture.

First, given the backdrop established in the previous paragraphs, a one-quarter reduction (≅100 calories) of the most water-intensive component of the average U.S. diet, red meat, exchanged for other grain-based foodstuffs, could singlehandedly free up 500 liters water. This is approximately equal to our entire current residential/domestic consumption (calculation: 100 meat calories → 600 liters water; 100 'average' food calories →100 liters water; 600 - 100 = 500). A one-quarter reduction in meat consumption is not an arbitrarily chosen value. With other nations that have similar life expectancies and human development indices consuming meat in quantities at one-quarter below U.S. levels, e.g. Canadians or Italians (FAO, 2007 -- as cited in The Economist), the feasibility of such a shift is difficult to dismiss as simply conjectural or dependent on unrealistic goals.

Water in surplus calories. Beyond meat considered alone, there is a second area of water for potential recapture: the vast quantity of water tied up in the human caloric surplus that currently exists around the world, and individually on every continent, including Africa. By 2015, according to FAO projections, available calories worldwide will surpass 2900 per capita per day, while approximately just 2000 is the benchmark of adequate (or rather, desirable average target) intake. In the United States, the country with the highest per capita caloric availability, the USDA Economic Research Service estimated in 2001 the aggregate available food supply to be at 3,800 calories per capita per day, with 1,100 calories of that total lost to spoilage, plate waste, cooking, and other losses, leaving 2700 intake calories. The aggregate total of calories available in the U.S. has climbed 800 calories per capita per day over the past half century and the actual human intake level by ~500 calories of that 800, indicating ~300 in additional food waste (USDA). Assuming that we haven't become more active or morphed to metabolize energy differently in the space of two generations time, this constitutes a relatively new intake surplus on the order of 20% of our diet. And if we can accept the premise that the United States was not struggling at the edge of want or privation at the time of the USDA baseline reference in 1957, then at the very least a portion of those 800 recently added calories are available for conservation (300 from food waste + 500 intake).

Stated another way, vast amounts of agricultural production, and hence equally vast amounts of water consumption, are available for recapture from every percent of reduction in excess human caloric intake and/or food waste. Applying the conservative metric of one liter = one calorie, and further conservatively assuming that only half of the surplus intake and waste from 1957 onward (800 calories) is feasible for easy recapture, this would nonetheless constitute still at least 400 calories and, by extension, 400 liters of water per person per day (note that this does not tap the substantial food waste already found in the 1957 baseline reference). This is an amount approaching our entire per capita direct water consumption. Noting further that obesity is now routinely characterized as a major, or *the* major, public health threat of the 21st century, justification on health grounds alone could be found for initiatives in this direction. Driven by health-related priorities, the reduction and recapture goals could be significantly more aggressive than those proposed here (i.e. 600 or 750 calories instead of 400). Such conservation broadly viewed, far from being framed in the language of sacrifice or loss, may well be able to be framed as caloric intake ‘improvement’ or ‘optimization’ from public health, environmental, or economic perspectives.

Water in calorie consumption from excess weight. There is yet a third, not well researched or acknowledged area of food-based embedded water that is available for recapture, found in the marginal caloric energy requirements of obesity (additional caloric need based on excess weight carried).

The high incidence of obesity and overweight in the United States, as well as in other OECD nations (recently in developing nations too), has spurred increased study and tracking of human weight. While data on the number of overweight and obese individuals is widely circulated, indications of exactly how many pounds of excess weight is in existence is harder to find. An oblique reference in a CDC news briefing in 2009 identified the average amount of excess weight carried by Americans at 23 pounds per person. The unsupported reference was calculated in this investigation for corroboration (see Appendix G). Use of a midrange ‘overweight’ body mass index designation (BMI) of 28 for average height males and females and a BMI of 33 for ‘obese’ designation (the obese category is unbounded on the upper end), yielded 30 (overweight) and 57 (obese) pounds respectively, of weight beyond a normal weight reference level (BMI 22.5). Applying those weights to the current breakdown of the CDC’s normal weight, overweight, and obese percentages of the population (2010) shows the average American adult (combining male and female values for convenience) to be about 30.5 pounds overweight – somewhat more than the CDC statement but in the same ballpark. A second calculation method (see Appendix G), again using CDC data and standard BMI tables, yields an average adult excess weight of 35.5 lbs. Using the most conservative of the three numbers (23 pounds), multiplied by 3500 calories per pound, the product is approximately 80,000 calories per person. At a 1 calorie to 1 liter ratio the equivalent is 80,000 liters of embedded water. However, the water behind those 23 pounds represents only the relatively static, accumulated figure. More significant is that the human body requires about six calories per day for each marginal pound of weight carried (e.g. Calorie Calculator, 2012). Multiplying the most conservative average overweight of 23 pounds by 6 calories per pound, this comes to an average 138 calories of additional food consumption *per day* for each overweight person. In other terms, U.S. obesity by itself comprises an *ongoing* water consumption footprint of approximately 138 liters of water per person *per day*, apart from the caloric and water consumption to add the weight in the first place. This is equivalent to a substantial fraction of U.S. per capita domestic water use, and is actually higher than the total per capita domestic water consumption for many European nations, not to mention most developing nations. Using the middle value of the three overweight calculation results rather than the most conservative would point to a daily water footprint of approximately 180 liters, and the highest 210 liters.

Connecting the dots between food, water, scarcity, and disparity

These three water recapture areas described, 1) at 500 liters or more, and 2) at 400 liters or more, and 3) at 138 liters or more, sum to >1100 liters of daily per capita footprint water available for reclamation when and if needed.

Table 6-A. Water available for recapture from food.

Water source	**Minimum estimated available lpcd**	**High estimated available lpcd**	**Note**
Convert small portion of red meat calories to grain base (total calories constant) ***min =(100 x 6) -100 cal;*** ***max =(250 x 6) – 250***	500	1250	Based on 6 to 1 caloric advantage for grain as compared to meat created from grain
Reduce total food waste to pre-obesity epidemic levels (based on current food creation of 3800 calories per person vs 3000 in 1950s) ***Min reduction = 400 cal; max = 800***	400	800	Partial/complete return to caloric intake and food waste levels of late 1950s
***Reduce overweight to* pre-obesity levels min = 138; max = 210**	138	210	6 extra calories needed daily to sustain each pound of overweight in population
***Total lcpd recoverable* from unhealthy or waste calories**	1038	2260	

There are several lines of thought useful to the water-informed and conversant person to be drawn from this information. The first is that the relentless rhetoric of impending water shortage and crisis is demonstrably suspect. This evidence suggests an extensive worldwide latent surplus of both water and food available simply by re-routing to people a small portion of edible grain that is currently fed to animals or processed to be dispensed at a gas pump. The agitated discussion of water framed in the language of imminent crisis could be driven by any number of factors. Three are mentioned here: First, there is a pronounced media 'alarm bias' in reporting that distorts data and discussion in a quest to generate interest (e.g. Stossel, 2007), mirroring a documented null hypothesis negative bias in academic publishing (e.g. Koren & Fernandez, 2010; Vergano, 2013). Second is a simple lack of conceptual and contextual understanding across the water consumption categories and between the water/food interface, along with a lack of analysis integrating water footprint data with caloric intake data. Equating food choices with dramatic water savings is not an intuitive matter, at least not now (intuitive understanding is not completely immutable however: doctors promoted cigarettes 70 years ago, something 'intuitively' incongruent today). Third is a possible sense among some stakeholders in water sectors that the specter of shortage and crisis is needed as a tool to mobilize efforts toward water conservation or other environmental action, or to attract attention and resources to water conservation related activities (See Chapter 10 water conservation section and Syme et al. for additional discussion).

Lilley, McNally, and Yuen (2012) in *Catastrophism* have given a succinct definition to the tendencies broached above:

> Catastrophism presumes that society is headed for a collapse, whether economic, ecological, social, or spiritual. This collapse is frequently, but not always, regarded as a great cleansing, out of which a new society will be born. Catastrophists tend to believe that an ever-intensified rhetoric of disaster will awaken the masses from their long slumber – if the mechanical failure of the system does not make such struggles superfluous.

Within the public health field, Jones and Greene (2013), in a study of our perceptions around coronary heart disease, have explored more generally the substantial power of the narratives of catastrophism (and triumphalism) to both distort reality and shape policy based on those distortions.

A second line of thought is that the rhetoric of water scarcity is not simply inaccurate, but that it deflects attention away from and obscures real and more important water issues. The evidence of available footprint water to ease potential water shortfall does not mean there is no benefit to water conservation, but perhaps the most compelling argument for careful use of water is the less gripping but more complex and morally troubling issue of disparity. The arguments for water conservation or investment in domestic water do not need to rely on a spurious specter of shortage to justify action. In a corollary with food that makes more sense as the linkages between food and water are developed, millions of people are without access to sufficient quantities of either food or water even as surpluses exist for both around the world. This shifts the problem definition from one of supply and availability to one of justice, allocation, and distribution.

The world food situation is illuminating for looking at water prospects on multiple levels. Recent FAO data (2010) indicated that there are approximately 900 million chronically undernourished people worldwide. This number, in absolute terms, has remained near constant even as both absolute and per capita caloric availability has increased on all continents, in some cases dramatically.

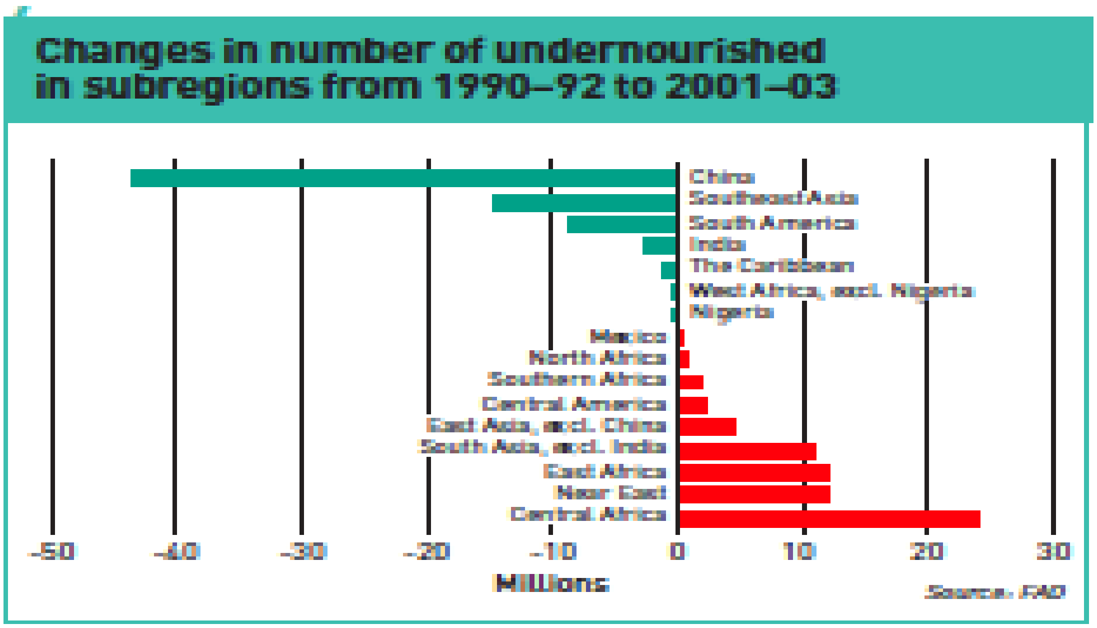


Figure 6-3. Undernourishment changes, some for better and others for worse (FAO, 2006)

In terms of proportion of total population, hunger has shown recently a modest decline, but it is clear from the data that making (and wasting) more food is, at best, an inefficient means to reduce hunger (see fig. 6-10). Current average per capita caloric availability is at 2300 for sub-Saharan Africa, the region most precarious. As pointed out by food experts, inability to produce or purchase food, i.e. poverty, is the real reason for undernourishment, not unavailability of food (e.g. FAO, 2006; World Hunger, 2012).

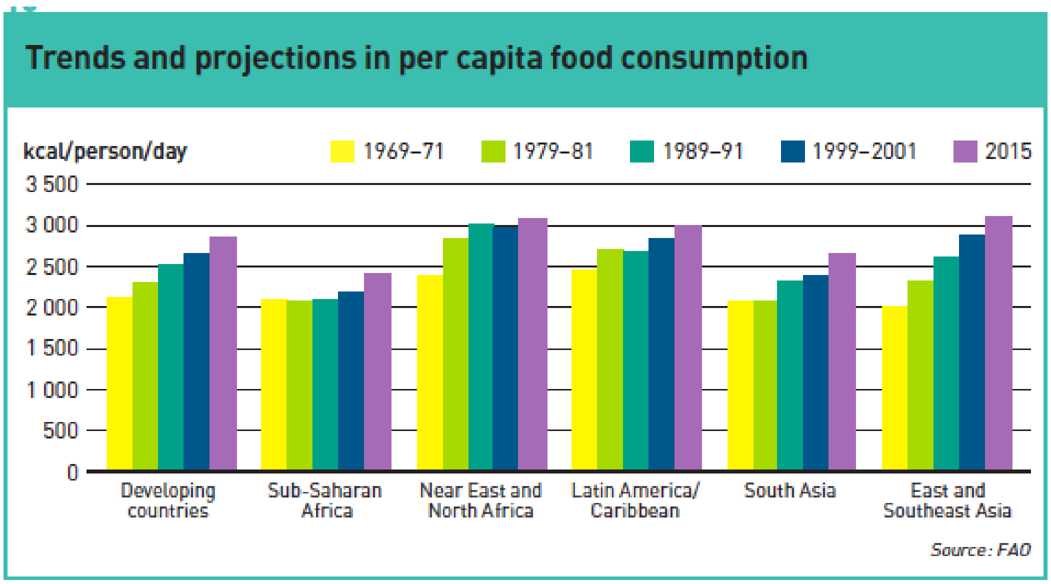


Figure 6-4. Forty five years of increasing food consumption

FAO (2006)

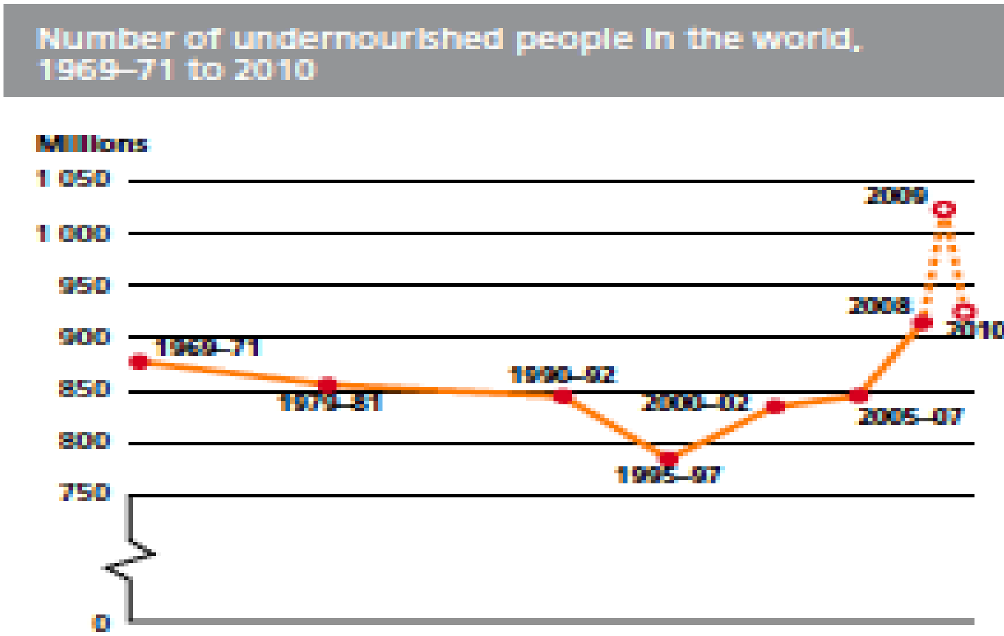


Figure 6-5. A forty year trend of undernourishment

FAO (2010)

Depending on the time frame of trend analysis, FAO data could actually be used to point to increasing undernourishment against a backdrop of increasing absolute and per capita caloric availability. A twenty-year analysis horizon, for example, would show a discernible positive correlation between increased per capita food production and increased number of undernourished people. This is not to hypothesize that growing *less* food will reduce hunger but only to emphasize that arguments for more food as a strategy against hunger are dubious. A true correlation, if it exists, appears to be arguably in the opposite direction, even over two generations.

The food-to-water comparison is not just an evocative analogy. Because in a very real way food is composed largely of water, disrobing a false argument about a shortage of food by extension does much the same to arguments about a shortage of water. While the full range of implications of the food-to-water relationship is not clear, there is enough data to challenge conventional assumptions regarding shortage of both food and water. An emerging discussion of combined food and water linkages has been termed the 'the water, energy, and food security nexus' (e.g. Hoff, 2011).

Conclusions/actions:

-There are not simply incremental, but vast water savings available in the footprint category of water consumption based on: inefficiencies in food production, excess human caloric intake worldwide, and increased food waste. The scale of water savings dwarfs the entire domestic water consumption category. This doesn't eliminate, but potentially changes the nature of the oft-stated need for water conservation at the domestic level, with the latent capacity in the water footprint providing an enormous demand buffer.

-The data support potential footprint water recapture of 500 to 1250 lpcd for a slight reduction in meat consumption (balanced with increased grain consumption), 400 to 800 lpcd from reducing food waste and per capita caloric intake to pre-obesity epidemic levels, and 138 to 210 lpcd from the marginal caloric needs of carrying excess weight on humans, for a total of 1038 to 2260 lpcd of recoverable footprint water. Apart from the liters themselves, this data indicates far greater elasticity of supply than is generally portrayed.

-The notion of aggregate water scarcity, as disseminated, is misleading. Though water scarcity is more telegenic, water disparity (whether in the presence of abundance or local scarcity) appears to be a more significant problem than scarcity. Prominent attention to scarcity may obscure or hinder addressing issues of disparity.

-Seemingly obvious arguments for conservation of water at the domestic level may need refinement to accommodate the reality that domestic water is not where the center of gravity of water consumption lies. There is ample justification for wise use of water, rooted in human health and resource-distribution-disparity concerns, but possibly not in effective scarcity.

-Human water consumption discussion is colored by the rhetoric of catastrophism, to the detriment of clear understanding.

-There may be relevant public health linkages between the worldwide obesity health threat, excess food production, and water conservation (with a focus on *optimization* of food quantity and type as opposed to efforts to *increase* food production). In the U.S. a shift of human caloric intake to a level that would reduce overweight/obesity challenges in the population would simultaneously save an amount of water nearly equivalent to our entire domestic consumption. Separately, a reduction in the U.S. of meat consumption of about one-quarter of current levels (to that of Canadians or Italians) and replacement with grain-based foods or vegetables would save an amount of water equivalent to or greater than our entire domestic consumption.

-There could be a new dimension to term ‘water for health’. Does the possibility of action for reduction of obesity, motivated by health goals, provide an opportunity for incentivizing water recapture?

-The data illustrating that we are not eating approximately three-fourths of food produced (in the U.S) has implications for the food security discussion. Does this open new pathways in thinking how to ensure a secure food supply, or allow a relaxing of concern over shortage prospects? Possibilities exist for framing thinking more in terms of resilience, risk tolerance, or assets (avg. ~40 days accumulated calories carried on U.S. population). Justification of possibility may exist for reframing as economic issue rather than food issue, with money rather than food availability the limiting factor.

Chapter 7: Water for human waste carriage

Introduction to the modifiers of domestic consumption

The preceding chapters -- defining the investigation project, framing the state of the literature, and establishing conceptual foundations -- could be considered a PART I of this work. Chapters 7 through 16, covering in depth the modifiers of domestic water consumption correspond to PART II, and constitute the central research interest of this project. The last two chapters – 17) Results, and 18) Discussion -- are the synthesis that correspond to PART III.

Dry sanitation or flush toilets: two divergent paths

Whether we inhabit a rich urban sphere or a poor rural one, we all drink, bathe, cook, wash, and clean with water. A fundamental divide exists, however, between those who use water for human waste removal and those who do not: the world of the flush toilet versus that of the latrine. It is a major modifier of consumption and an area of major confusion. Because each side of the divide is tied to very different profiles of water consumption, it is difficult to evaluate or assign appropriate consumption levels for a given situation without explicitly taking this variable into account. Nonetheless, an overview of the literature indicates that it is common to find water consumption references and guidelines with no explicit indication in the figures of whether water for human waste carriage is intended; even the Millenium Development Goals fail to adequately distinguish between water-driven (flush toilet) and dry sanitation solutions in their criteria of improved sanitation.

High-income nation consumption bracket

There is a wide range of consumption within the European, Japanese, and North American regions, but with a relatively high lower end compared to the developing world: it lies generally above 120 lpcd (~32 gal). The chart (Figure 5-7, pg 43) derived from UNDP human development report data (2006) illustrates the gulf between the predominantly ‘flush toilet nations’ and poorer nations where dry sanitation is more common. According to this data, the United States is the highest consumer per capita, at just under 600 lpcd. From Germany upward (number 10 in the ranking), the list includes exclusively wealthier, predominately urban, OECD (Organization for Economic Cooperation and Development) member nations, where dry sanitation for human waste removal is low (the list does include Mexico, arguably a developing nation, but which in fact has belonged to the OECD since 1994). In the United States, for example, as of 1990 dry sanitation (outhouse or privy) had fallen to only 1.1% of total households, a negligible level. (See appendix F for a note on U.S. and Alaska dry sanitation numbers). This stands in stark contrast to the bottom of the UNDP list, with developing countries at 25 lpcd or below of water consumption, and where dry sanitation is common or dominant (discussed in the next section).

For the United States, the REUWS and other sources attribute the largest single portion of indoor domestic water use to the toilet, reporting that 27% of all U.S. indoor water use goes to the toilet (or 11% of average combined indoor and outdoor residential use). Other OECD nations have similar percentages: for example, Austria 22%, Holland 29%, and Germany 32% (Aquaterra, 2008).

These percentages of domestic water use, while substantial, do not alone account for the difference between the OECD and the developing nation bracket. The flush toilet is presumably closely tied to multi-tap indoor plumbing. This is in contrast to all lower service levels (i.e. single kitchen tap, single yard tap, or public source) where there is much lower consumption and dry sanitation is the norm.

It should be noted that while percentages of water use for flushing are similar between North America and Europe, the totals on which those percentages are based are quite different. For example, the 27% of indoor use attributed to the toilet in the U.S. equals approximately 70 liters (REUWS, 1999); the 32% attributed to the same use in Germany is 37 liters (Aquaterra, 2008).

Developing nation bracket

Developing nations struggle with dichotomous water demand profiles: in large cities residential water use does include flush toilets and may mirror that of wealthy nations, while simultaneously the poorer rural populations routinely have extremely low water consumption levels and dry sanitation (if any sanitation infrastructure at all). Following is a compilation by Abu-Ashour and Al Sharif (2010) of some widely recognized developing world water consumption standards (Figure 7-1). These standards constitute a manifestly different range from those in the OECD bracket, and appear also to entirely ignore the urban reality within the developing world.

Minimum water requirements	reference
20 Lpcd from a source within one kilometer of users dwelling	WHO/UNICEF Joint Monitoring Programme, (WHO, 2000)
15 Lpcd for disaster relief	SPHERE Project (SPHERE, 2002)
20 Lpcd minimum criterion for water supply	Carter et al. (1997), WELL (1998)
50 Lpcd basic water requirement for domestic water supply	Gleick (1996)

Figure 7-1. Prominent international minimum water supply values.

As reported in Abu-Ashour and Al Sharif, (2010).

Figure 7-2 shows a range of water consumption values from a developing world perspective and provides corresponding functions for each level. The basic domestic components top out at 50 lpcd, and the values beyond that could be questioned. Growing food in any substantial quantity generally requires more than10 lpcd. Likewise, if 'sanitation and waste disposal' means a flush toilet, 10 lpcd is not a realistic figure. If it doesn't contemplate a flush toilet, then 10 lpcd is too much, as only a very small quantity of water should be used for cleaning latrine surfaces (to avoid additional liquid in the latrine vault).

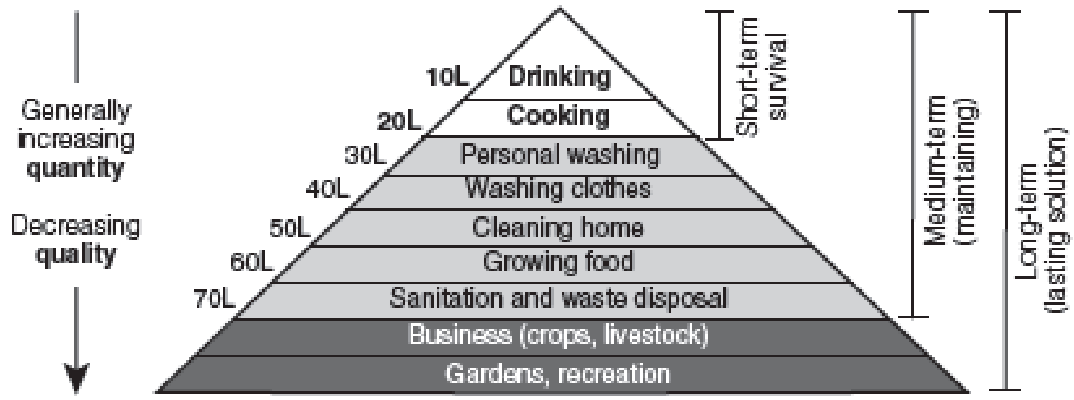


Figure 7-2. Functional hierarchy of water need with consumption values.

Source: Water, Engineering and Development Centre; Loughborough University

The overall dichotomous profile for developing nations is exacerbated by drivers pushing consumption toward extremes for both the urban and rural realities. On the urban side, lack of resources for best water-saving technology and for fixing water distribution system leaks mean that poorer urban areas can actually see demand equal or exceed that of wealthy urban areas (e.g. Walker & Velasquez, 1999). On the rural side, water consumption is low, not just for the absence of a flush toilet. Lower service delivery levels and hardship in securing water (e.g. long distances traversed on foot, wait times at dispensing points) can suppress demand to below the even very modest amounts indicated by SPHERE as a basic minimum for life, as illustrated in the figure below (see appendix I for notes regarding energy burden of manual water transport).

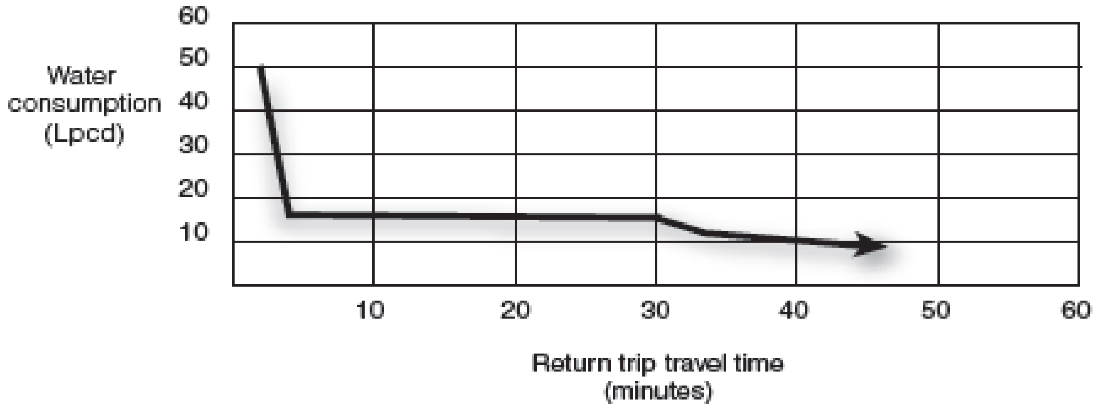


Figure 7-3. Demand suppression: relation between water consumption and distance

Source: Water, Engineering and Development Centre; Loughborough University

Though the urban-rural divide pushes developing nation consumption patterns towards extremes on both tails of the distribution, demographic trends of rapid urbanization would appear to push the overall distribution of developing nations toward higher total consumption for the future. The UN (2011) projects that developing nation urban percentage will go from 47% to 64% of total population in the next two decades, meaning more need for flush toilets as well as general consumption patterns that look more like that of the OECD nations (given the current lack of good substitutes for flush toilets in urban settings).

The syncretic approach

A rough quantification of the urban or rural and OECD or developing nation water use could be summarized as two distinct and discontinuous ranges: for the rural poor it can be framed by 20 to 50 lpcd; urban and/or wealthy areas by 120 lpcd and above. The application of consumption numbers based on dry sanitation in situations where water for flush toilets is needed will create serious shortfalls in meeting demand, with potential public health consequences. A different problem occurs when consumption numbers that assume the use of a toilet are applied to settings where sanitation is not water-based. The surplus creates the potential for wasteful allocation of a valuable resource.

The syncretic approach of trying to find a middle ground between these two numbers applicable for both situations does not seem rationally supportable but can occur (e.g. Gleick, 1996; SANAA, 1999). Using the simple average between these ranges is a false indicator of central tendency, which yields a misleading number suitable for neither situation: higher than necessary for situations where simple dry sanitation is in place, yet clearly inadequate for situations where flush toilets are used. There are isolated cases where the use of an in-between number may be appropriate: in transitional or peri-urban communities some houses are fitted with toilets where others are not (yet); here, an in-between value could be justified at the system design and water allocation level. In these settings, user data regarding individual household sanitation may not be readily available without door-to-door surveys, and to differentiate water allocations based on the 'toilet or no toilet' factor has the potential to present engineering and/or social challenges in service delivery.

It should be noted that the average figures can be deceptive at the macro level as well. National data on domestic water consumption for middle income or transition countries showing seemingly in-between values is almost certainly a case of aggregated data obscuring the bimodal distribution: the existence of large rural populations living with very little water and roughly equivalent urban numbers living with OECD consumption levels. There are no secret super-efficient toilets or dry sanitation solutions adapted to cities in widespread use in the in-between countries.

One way to eschew the need to evaluate the ‘dry sanitation or flush toilet’ issue at the household level is to set water consumption design numbers based on the size of the community. In developing countries, a reasonable assumption can be made that inhabitants of small rural communities do not make use of flush toilets, where in larger urban areas the assumption can be made that toilets are used. UN Millenium Goal 7 monitoring (2012) corroborates a large urban/rural disparity in improved sanitation, though the data is not specifically broken down by flush toilet vs latrine. For example, different rural and urban assumptions can be found in the standards for the national water authorities in Honduras and Bolivia without specific mention of toilets (SANAA, 1999; Ministerio de Desarollo Humano de Bolivia, 1996). In the case of Honduras, the design allocation for communities of less than 3000 inhabitants is set at 95 lpcd (25 gpcd), midway between dry and flush. In Bolivia, a sliding scale according to population is used with design allocations of 30 to 90 lpcd permitted in communities of less than 500 inhabitants, 50 to 120 lpcd in communities up to 5000, and 150 to 350 lpcd in cities with a population greater than 100,000.

Anchoring context of dry sanitation and flush toilets

Flush toilets and dry sanitation each have significant and fundamentally different constraints to their deployment. A flush toilet requires generally between 6 and 19 liters (1.6 to 5 gal.) of water per flush, with the range based on whether older technology or the best widely available proven technology is used. The REUWS (1999) found ~5 flushes per household/person per day with a mean water volume of 13 liters (3.48g) per flush. The REUWS preliminary update in 2012 indicated modest declines in overall residential per capita water consumption (~20%), due in part to increasing diffusion of more efficient (lower volume) flush toilets. Average toilet consumption fell by 29% for the one city revisited so far, which if the variables of occupancy and number of flushes per capita held constant would mean the water volume per flush is now 9.2 liters or 2.44 gallons. Whatever the requirement, however, adequate water to flush is non-negotiable from both a public health and human sensibility standpoint.

Dry sanitation, for its part, requires land in excess of the typical urban lot size. Latrine design manuals specify (e.g. WHO, 2005) separation distances of up to 30 meters from wells or other open water sources to avoid contamination and 8 meters from houses for odor dispersion. A ground level space is needed for the latrine structure along with an underground vault for soil absorption of feces and urine. These requirements preclude latrine use in densely populated urban areas, particularly multi-floor dwellings. Experimental technologies such as composting toilets are not considered here given the lack of success so far in large-scale implementation.

A little noted, yet noteworthy characteristic of the flush toilet from a water consumption perspective is that where it is used it frequently supplants *and simultaneously eliminates* other less water intensive solutions – it does not coexist easily with dry sanitation. For example, in a U.S. small town setting, when piped water and sewer service becomes available at the household level, not only are dry sanitation solutions (outhouses) considered no longer necessary, they are liable to be actually prohibited (e.g. City of Owatonna MN, 2003). It is not impossible to find situations where an outhouse is legal in a given rural jurisdiction, but if the same structure is located just over the line inside an adjacent urban boundary, it can be described with a pejorative term like "a nuisance and menace to public health" (City of Westhope, ND, 2012). The net result is that there can be few or no adequate less-water-intensive substitutes or backup solutions once toilets are in place, fostering simultaneously higher water consumption levels and demand inelasticity. Whether a dry sanitation arrangement such as a privy or outhouse is *per se* a menace to public health is a matter of continuing discussion, but no one debates that the circumstances of a flush toilet without adequate water for its operation is a grave situation. In summary, if the water use context includes flush toilets, then the water allocation data driving decisions must be specific to it and the demand assumed to be relatively inelastic.

Water for waste carriage and the Millennium Development Goal 7

The WHO/UNICEF sponsored Joint Monitoring Program for the MDG 7 (Millennium Development Goal 7, covering access to water and sanitation) has provided what are perhaps the most internationally visible criteria for what constitute improved sanitation solutions. The JMP definition for improved sanitation is that the sanitation facility "hygienically separates human excreta from human contact." There is no mention of water use or flush toilets specifically as part of the sanitation goal. While in the minds of many a flush toilet occupies a superior technological, hygienic, and aesthetic position to that of a latrine, and certainly can be seen as a fundamentally different solution by virtue of the fact that the former uses water and the latter does not, for the MDG flush toilets are lumped together with latrines. The groupings occur exclusively along the functional success in achieving separation of excreta from human contact.

'Unimproved' or inadequate sanitation includes 1) open defecation without facilities, 2) constructed sanitation facilities that fail to hygienically separate human waste from human contact (e.g. hanging latrines or toilets, latrines not on a concrete slab, honey bucket systems), or 3) those facilities that are otherwise hygienically adequate, but are shared by two or more families. The 'improved' sanitation designation is for those solutions that meet the single-family-per-facility and the hygienic-separation criteria. The JMP cites (together) as examples flush or pour flush toilets connected to a sewer or septic system, VIP latrines, or conventional pit latrines on concrete slabs.

MDG Target 7c calls on countries to halve, by 2015, the proportion of people without sustainable access to safe drinking-water and basic sanitation. In order to estimate access to basic sanitation and to safe water JMP is required to use two MDG indicators:

- proportion of population using an improved sanitation facility, urban and rural;
- proportion of population using an improved drinking-water source, urban and rural.

Because definitions of improved sanitation facilities and drinking-water sources can vary widely within and among countries and regions, and because JMP is mandated to report at global level and across time, JMP has defined a set of categories for "improved" and "unimproved" sanitation facilities and drinking-water sources that are used to analyse the national data on which the MDG trends and estimates are based.

An improved sanitation facility is one that hygienically separates human excreta from human contact. An improved drinking-water source is one that by the nature of its construction adequately protects the source from outside contamination, in particular with faecal matter.

Figure 7-4. Millennium Development Goal 7, sanitation and drinking water options

Source: JMP of WHO/UNICEF (2010).

By JMP estimates (2010), approximately 4.5 billion persons have acceptable sanitation using these criteria, and 2.5 billion do not, constituting a major shortfall justifying aggressive efforts to increase improved sanitation coverage worldwide. However, in an investigation eerily evocative of events leading to the Great Stink of London a century and a half ago, Baum, Luh, and Bartram (2013) documented the deficiencies of sewage treatment around the developing countries of the world and they throw up a red flag on the idea of rapidly pursuing what would ostensibly be considered the gold standard of improved sanitation – the flush toilet. Based on their research, they propose drastically lower worldwide sanitation coverage numbers. Finding that in the developing world an alarming proportion of water systems that enable the use of flush toilets do not have adequate sewage treatment components in place, the authors consider that such systems which discharge untreated sewage directly into the environment fail the JMP criterion of "hygienic separation of human excreta from human contact." Currently, interpretation of the separation criterion is at the individual user and immediate surroundings level. Baum, Luh, and Bartram take a more ecological view in considering downstream or adjacent population exposure to excreta in untreated sewage. Application of this more stringent standard of interpretation, justified because of the risk untreated sewage poses for downstream users and water supply intakes, would push much of what constitutes the supposedly best sanitation solution out of the 'improved' category. In the authors' analysis, by this standard, our worldwide improved sanitation coverage would need to be adjusted down from 4.5 billion to 2.8 billion, or just 40% of the global population. From a practical perspective, the result of such a shift would be more transparent linkage of flush toilets to their potential negative externalities, permitting better-informed choices in evaluation of solutions, and additional impetus for ensuring that sewage treatment is included in water delivery and sanitation project budgets. However, accepting the huge numerical write down in progress toward this key development goal will be a bitter pill to swallow at both the strategic policy and the MDG implementation levels.

Budgetary disconnect

The situation of inadequate wastewater treatment was foreshadowed by Winpenny (2003), where in citing Global Water Partnership data, he noted a gross shortfall in financing for wastewater treatment in the developing world, with treatment cost far surpassing the direct requirements of water, sanitation, and hygiene combined. Financing for water supplies in the developing world was at the time of the article adequate to continue progress toward the improvement goal, at an annual 13 billion US dollars. Yet for the other end of water supply pipeline -- provision of wastewater treatment -- the unmet annual need was then 56 billion dollars, a figure over four times that to provide running water. Quadrupling the expense burden of water supplies is inconceivable in the realm of existing developing world water and sanitation budgets, meaning many water delivery schemes may well get built without adequate waste treatment.

Ironically, the so-called ‘improved’ sanitation of flush toilets without sewage treatment potentially creates not just a health risk but also a negative feedback loop between the water supply and sanitation halves of the MDG 7. Polluted and untreated water from so-called improved sanitation based on water imperils existing and future water supplies, then the compromised water sources make less feasible the development of new water delivery systems, systems that would in turn permit the installation of improved sanitation solutions.

Conclusion/action.

-There is a water consumption divide or discontinuity between water use situations characterized by dry sanitation and those with flush toilets. On a practical level, if a person states that they make use of a dry sanitation solution, the likelihood is that that person consumes 50 liters or less per day, and if a person indicates that they use a flush toilet, 100 liters or more. National consumption numbers indicating a use between 50 and 100 liters most likely reflect an averaging of 'rural-dry' and 'urban-flush' profiles.

-In a modern U.S. residence, the toilet is the single largest indoor use, but contributes on the order of 70 liters, or only 11%, to overall consumption. In Europe the overall consumption can be less than half that of the U.S., and the toilet consumption much less as well, but still is the largest consumption component.

-The water consumed by the toilet itself does not explain the entire water consumption gap between dry sanitation and flush toilet households, but is the most emblematic characteristic of a high water consumption profile.

-Tension exists between dry sanitation and flush toilet solutions, with toilets associated more closely with wealthier urban settings and the existence of toilets prejudicing latrine use where piped water is available.

-There is widespread specification of water allocations for people or homes in norms, guidelines, and requirements *without explicit mention whether the allocation is intended for use of a toilet*. Because of the substantial consumption gap between dry and flush sanitation, the two circumstances should be handled separately, as binary options in a decision tree (i.e. 'x' quantity for dry sanitation choice and 'y' quantity for flush toilet choice). This recognizes and appropriately handles the discontinuity between the two realities.

-The JMP for the MDG Goal 7 does not differentiate between water based and dry sanitation solutions. The lack of an international taxonomy that separates dry sanitation from flush sanitation makes application of this water consumption modifier somewhat more problematic.

-When flush toilets are used in water systems that do not have sewage treatment, their use can contaminate the very water supplies that enable able the deployment of toilets. This feedback loop of negative externalities of flush toilets has been highlighted recently by Baum, Luh, and Bartram and constitutes a distorting influence on sanitation option decision-making. The untreated sewage contamination issue also calls into question the existing estimates for worldwide sanitation coverage if the criterion of “separation of human waste from persons” for improved sanitation is strictly interpreted. According to Baum et al., worldwide coverage should be adjusted downward from 4.5 billion to 2.8 billion.

-Closing the untreated sewage gap in developing countries is a non-starter under current water sector investment/funding/financing scenarios: the annual shortfall is >$50 billion, requiring a four-fold increase of investment in order to address.

-Where no sewage treatment exists, the stepping up in service level (with increase of water consumption) to include flush toilets, may actually mean increased health threats to users and others, rather than health benefits.

-Clarity is needed in water norms, guidelines, and requirements in stating whether water consumption allocations include toilets, rather than left implicit. This would require a two-tier classification system and is a sensitive issue because explicit acknowledgement of toilet use would highlight differences between rich and poor, and urban and rural, and would require justification to populations.

-I believe that the ambiguity around the toilet or no toilet dichotomy in water allocations is specifically to avoid the need to justify the use of water for waste removal in comparison to dry sanitation.

-Awkward questions that make more difficult explicit discussion and rational decision-making regarding sanitation:

a) Does possession of a toilet, which requires water to operate, entitle the owner of said device to more water consumption than someone who does not have a toilet?

b) Is dry sanitation looked at with disdain in some quarters, as a poor person's toilet?

c) Will people sacrifice their drinking and bathing water to flush a toilet? What about someone else's?

d) How infrequently can toilets be flushed and still function without health and esthetic concerns (because of water shortfall)?

Chapter 8: Metering

Support for metering

By providing transparency and accountability to water consumption behavior, metering is widely considered to be a powerful modifier of consumption. In particular, utilities and their personnel are especially vocal in support of the use of meters, and the American Water Works Association explicitly advocates universal water metering. This position is motivated in part by considerations of water conservation, but revenue and water-use-tracking considerations also play a role. Utilities routinely consider metering as the first of measures for demand-side management in water conservation efforts (e.g. Florida Rural Water Association, 2007).

The American Water Works Association (AWWA) recommends that every water utility meter all water taken into its system and all water distributed from its system at its customer's point of service. AWWA also recommends that utilities conduct regular water audits to ensure accountability. Customers reselling utility water – such as apartment complexes, wholesalers, agencies, associations, or businesses – should be guided by principles that encourage accurate metering, consumer protection, and financial equity.

Metering and water auditing provide an effective means of managing water system operations and essential data for system performance studies, facility planning, and the evaluation of conservation measures. Water audits evaluate the effectiveness of metering and meter reading systems, as well as billing, accounting, and loss control programs. Metering consumption of all water services provides a basis for assessing users equitably and encourages the efficient use of water.

An effective metering program relies upon periodic performance testing, repair, and maintenance of all meters. Accurate metering and water auditing ensure an equitable recovery of revenue based on level of service and wise use of available water resources.

Figure 8-1. American Water Works Association policy on meters

American Water Works Association

Skepticism around metering

However, not all reasoned voices are in favor of meters. Staddon (2011) has convincingly disputed at least some of the evidence that metering can meaningfully reduce water consumption in the long-term and concludes “the research suggests there is little evidence that compulsory universal metering can achieve either the water conservation or social equity goals articulated by government [utilities].”

In poorer rural areas of the developing world, water meters are sometimes regarded by residents with skepticism and hostility as they are emblematic of the commoditization of what has been historically a free public or common good, like air (e.g. Johnson, 2003; Davis, 4 June 2013; Staddon, 2011). Veering further into political symbolism, metering can be seen by some not only as a tool of capitalistic encroachment upon traditional cultural values through *commoditization* of water, but also as a Trojan horse for *privatization* of water efforts (e.g. Ouellet, 2005; Davis) -- still a sensitive topic a decade after the Cochabamba and Soweto water protests.

Prevalence of metering

In spite of strongly voiced sentiment by water utilities for their placement everywhere, prevalence of metering remains uneven around the world. For the United States, it is now high though not universal. In a random survey of 200 North American water utilities, Rockaway (2011) identified three that used flat fees for residential consumption rather than meters, corresponding to a prevalence of ~98% (Anchorage, Alaska -- not one of the surveyed cities -- is also unmetered). In a comparative study of water consumption of several European nations, Aquaterra (2008) indicated metering prevalence of 33% in England and Wales, 100% in Denmark, 89% in Finland, 96% in the Netherlands, 99% in Germany, and near 100% in Austria. Staddon (2011) indicates about two-thirds of OECD member countries meter more than 90% of single-family houses, but claims that the last 10% of coverage to achieve universal metering is controversial everywhere. Metering prevalence data for developing countries is more sparse. Zhang and Brown (2005) characterized residential metering in Beijing as near universal. The Seimens Green City Index for Latin America reports residential water metering for 13 of 17 cities studied. The Index report for Africa found metering programs “either planned or implemented” in 14 of 15 cities. And in Asia, metering was described as near universal in the Index report. Some data on metering prevalence is suspect due to the fact that use of a single meter for multi-unit dwellings (apartment buildings) can be often counted as ‘metered’ (e.g. Aquaterra, 2008; Zhang and Brown, 2005). This potentially creates a commons dynamic (Hardin, 1968), which would confound the expected individual rational-best-interest conservation dynamic of single-household metering.

Data for water savings from metering

Data on how much water can be saved through the use of meters varies widely. The authors of the Aguaterra study (2008), focused principally on England and Wales -- where there are large populations of both metered and unmetered homes -- found water consumption an average 16% lower in homes with meters, drawn on data from 23 communities. Limited data from Finland showed a 20% difference between multi-unit buildings with and without individual unit metering (Aquaterra). Staddon (2011) cited studies showing 10% to 16% water savings and mentions with some skepticism claims (by advocates of metering) of up to 20%.

In less-strictly managed water systems in the developing world, anecdotal accounts claim up to 80% reductions in water consumption after the installation of meters in a given community (e.g. personal communication Ozushi Shinizu, March 2011, SANEPAR [a Brazilian water utility]), though that was acknowledged to be a greater reduction than the norm. Reductions of this magnitude could be due to unusual situations such as a landowner previously expropriating residential water for agricultural purposes, or broken water taps simply left open. In El Salvador, a ‘free-market friendly’ country and early adopter of metering in rural communities, a general estimate of water consumption savings is “nearly 50%” of pre-meter levels (personal communication Rodolfo Pacheco, 2001, CARE rural water program).

Sharratt (2001), in a water utility database analysis covering 309 municipalities and a population of 9.7 million throughout Ontario, Canada, found an average 28% lower consumption in metered connections. Sharratt also detected a small/medium vs. large municipality impact differential, with reductions of 31% for the small/medium municipalities and 19% for large municipalities (320,000 residents or more).

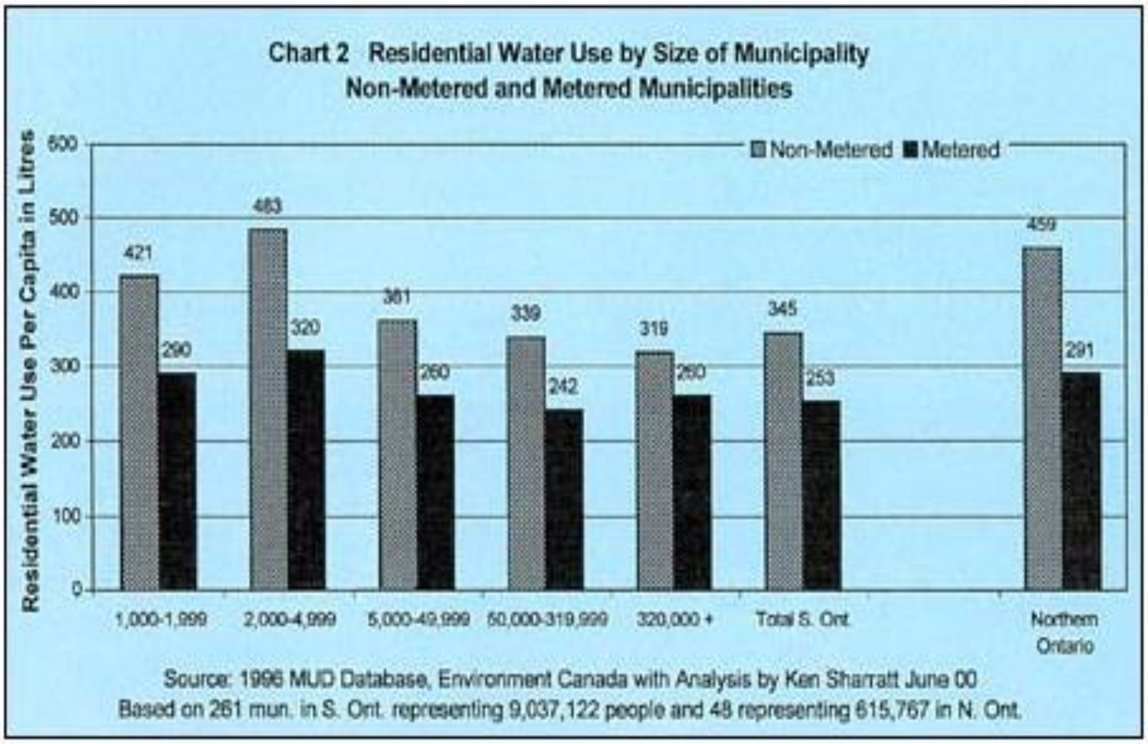


Figure 8-2. Effect of metering: small communities and metropolitan areas

Sharratt, 2001

Among the sources cited are cases where individual water customers were free to choose between flat fee and metering, virtually guaranteeing the introduction of adverse selection dynamics and hence some level of bias. The magnitude of potential bias is not clear. The direction of bias could be reasoned to cause reported voluntary metering effects to be larger than would be found in mandatory metering schemes, as those with the best possibilities to reduce consumption selectively opt for metering. This adverse selection would justify caution in drawing conclusions from data indicating larger-than-expected effects.

Public health impacts from water metering

While some claim that meters are ineffective and do not meaningfully reduce water consumption, others express concern that meters are too effective, reducing water consumption alarmingly to levels that compromise health. Against the backdrop of Esrey's (1991) seminal findings – that available water *quantity* is in some cases even more important than *quality* as a determinant of health -- these concerns cannot be discounted (Troy Ritter, personal communication, 2011; Staddon, 2011). Ritter reported evidence in rural Alaska villages that 'metered equivalent' water (volume pricing delivered by truck) at high price can suppress demand so severely that basic hygiene functions are at risk. This is echoed by Staddon, citing investigations in Abu Dhabi (Al Qdais and Al Nassay, 2001) and in Orkhei, Moldovia (Drozdov, 2002). It should be noted that in all cases the health-threatening restrictions cited were the function of a three-way intersection of volumetric pricing, relatively high rates for water dispensed, and relatively low incomes for the population examined.

To counter the possible health and general welfare impacts from water inaccessibility, metering initiatives can be and are frequently coupled to "lifeline" tariffs or allotments, or increasing block pricing schemes (e.g. Johnson 2003). Piggy backing on phone cards concepts, South Africa has pioneered the use of pre-paid card metering schemes, with a basic monthly free allotment built-in (see Figure 9-3).

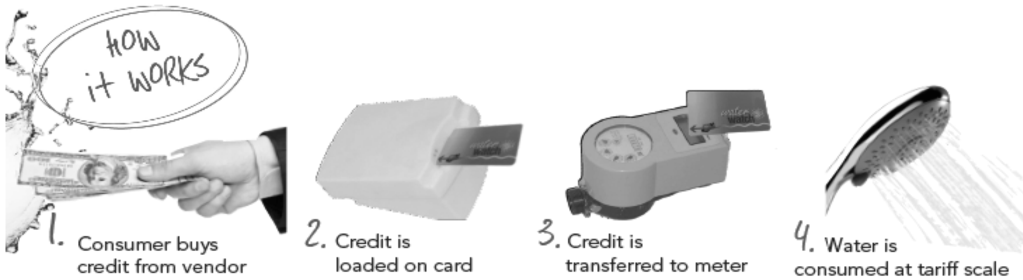


Figure 8-3. Promotional description for a pre-paid metering scheme.

Water Watch, South Africa

Not often heard in the discussion of metering pros and cons is that metered systems in the developing world can be much better at holding a water system in a continuous state of positive pressure, with manifest health benefits. Unmetered water systems can in the developing world function like sieves, where it is impossible to maintain water line pressure because of a veritable network of left-open taps and broken pipes. In these systems water is released into the system for a few hours a day only; the rest of the time no water is distributed and -- in a manner reminiscent of the 55 Broad Street pump -- water that has seeped from broken pipes into the ground during the pressurized phase runs back into the pipes, full of contaminants. Metering effectively creates incentive for water users to close taps and fix leaks on residential property, making continuous pressurization more viable. (See also *Intermittent vs 24/7 water systems*, Chapter 10).

Meters and more water than needed

Many or most water supply systems, when newly built or expanded, can count on a surplus of water in anticipation of future growth. Seemingly abundant supplies when the water systems are newly built can be highly misleading to users and potentially foster unsustainable use patterns when meters are not in place to check consumption. The downside of initial surpluses is an important countervailing factor to weigh against the design principle of ensuring enough water through the design life of the system when design decisions are being made factoring in population growth. Without meters the initial surplus, combined with unfettered access, can amount to ‘training communities to use more water than needed’, increasing the possibility of shortfall as the community grows into the design capacity of the system.

Conclusions/action

-Metering is a water consumption saving tool and the data appear to support claims of 10% to 20% in urban settings. In situations where food or animal production could be engaged from residential taps (rural lots), savings may be higher, possibly running to 50%. Claimed water savings beyond 50% of pre-meter use should be regarded skeptically except in unusual circumstances, such as when the baseline reference is egregiously high.

-To avoid negative public health impact, care should be taken to not set targets for excessive water savings.

-Water savings may not be the only justification for meter use – leak detection improvement, more equitable distribution, and more stable or increased utility revenue streams are also benefits against which their cost can be weighed. Additionally, where systems have been operated with intermittent service prior to metering and operate 24 hours per day after metering is in place, reduced contamination risks could be counted among the benefits.

-Water meters as emblems of commoditization and privatization can clash with collectivist and/or indigenous cultural traditions, particularly where water is treated as a common good or assigned a spiritual value.

Chapter 9: Service levels

Service level scale

This chapter brings together for comparison a collection of different sources' categories of service levels and information on the impact of the levels as a modifier of water consumption. The service level concept transcends the dyadic notion of water delivery conceptualized in the "improved vs unimproved" approach. It should be noted that the service level concept is most applicable to the developing world; for the one billion or so living in wealthy fully industrialized nations with across the board access to a first class water system, the distinctions of differing service levels have less relevance.

A generic "single strand" service level scale could be ranked as follows, from lowest to highest:

Unimproved source (river, pond, lake, spring, etc.)

Public open well, for buckets

Public well, sealed with mounted hand pump

Piped water supply, public tap stand

Piped water supply, yard tap

Piped water, single indoor tap, usually in kitchen

Piped water, two taps for bathing and kitchen, no toilet or sewer

Piped water, multiple taps, including toilet, no sewer

Piped water, multiple indoor taps, with sewer service

More sophisticated service level conceptualizations incorporate multiple dimensions of improved water supply, with water quantity consumed one of the most prominent, but not the only. Other main dimensions include: distance to source, time spent on travel to source, work required to extract water, public or private delivery, water quality, reliability or hours of service, number of persons per watering point, wait time at water gathering site, personal security of water gathering site, and number of water-using devices within home.

Figure 9-1 provides a snapshot of how service level can impact water consumption – note an almost perfect order of magnitude spread between lowest and highest service level in this example.

Type of supply	Average consumption (l/c/d)	Service level
Traditional sources, springs or handpumps	15.8	Communal
Standpost	15.5	Communal
Yard tap	50	In compound
House connection	155	Within house (multiple)

Figure 9-1. Empirical study of service level and consumption, Jinja Uganda.

WELL, 1998, cited in Howard and Bartram 2003

Though service level is a powerful determinant of consumption, it is often unstated and disconnected from consumption standards in national and municipal norms of developing countries, where varied service levels are likely to occur. This can render the norms misleading for making 'on the ground' water provision decisions when more than one service level option is possible (e.g. Servicio Autónomo Nacional de

Acueductos y Alcantarillados, SANAA, Honduras; Instituto Nacional de Agua Potable y Alcantarillados, INAPA, Dominican Republic, with limited distinction between service levels). Stated another way, norms can stipulate consumption levels for design of water supplies without any service level context. Given that service level is an essential and major determinant of actual consumption, this is a real problem. Some international standards are better at addressing this, but others can suffer from the same ambiguity (note Figures 8-2 and 8-3).

For lower service levels from public dispensing points, many information sources use a distance reference, others use collection time, and still others use neither. In Figure 9-2, Howard and Bartram provide both.

Service level description	Distance/time measure	Likely quantities collected	Level of health concern
No access	More than 1000m or 30 minutes total collection time.	Very low (often less than 5 l/c/d).	Very high as hygiene not assured and consumption needs may be at risk. Quality difficult to assure; emphasis on effective use and water handling hygiene.
Basic access	Between 100 and 1000m (5 to 30 minutes total collection time).	Low. Average is unlikely to exceed 20 l/c/d; laundry and/or bathing may occur at water source with additional volumes of water.	Medium. Not all requirements may be met. Quality difficult to assure.
Intermediate access	On-plot, (e.g. single tap in house or yard).	Medium, likely to be around 50 l/c/d, higher volumes unlikely as energy/time requirements still significant.	Low. Most basic hygiene and consumption needs met. Bathing and laundry possible on-site, which may increase frequency of laundering. Issues of effective use still important. Quality more readily assured.
Optimal access	Water is piped into the home through multiple taps.	Varies significantly but likely above 100 l/c/d and may be up to 300l/c/d.	Very low. All uses can be met, quality readily assured..

Figure 9-2. A range of service levels

Howard and Bartram (2003)

For interpretation between distance and time in water gathering, a walking speed of 5 km per hour (3.1 mph) can be used to translate the 1000 meter distance standard -- equal to 24 minutes round trip collection time. Also used are 25 minutes at 4.8 kph or 3.0 mph, and 30 minutes at 4.0 kph. The 5 kph figure seems to be the most commonly used reference in water service level data. As a point of reference, Bohannon and Williams (2011), in a meta-analysis of normal walking speed research for humans (41 studies, 10 countries), determined a median speed of 4.7 kph for adult females and 4.9 kph for adult males across the studies.

It should also be noted that occasional mention of vertical distance is made as a consideration in water gathering. In Figure 9-4, India norms indicate water points should be less than 100 vertical meters different from the home altitude. As a reference, data from Minetti, Moia, Roi, Susta, and Ferretti (2002), in a study of uphill and downhill locomotion, appears to indicate that the energy needed to traverse one vertical unit of distance is equivalent to approximately eight horizontal units.

Wright (1956), in a farm water and sanitation guide, provides a historical water consumption reference that indicates stability of service level values over time: he stipulated 45 lpcd for a kitchen tap service level and 151 lcpd for multiple taps in a modern home, little different from modern sources. Somewhat more recently, Hofkes (ed.) (1983) provides distance-based scale, running from 7 to 150 liters, shown in Figure 9-3.

Type of Water Supply	Typical Water Consumption (litres/capita/day)	Range (litres/capita/day)
Communal water point (e.g. village well, public standpost)		
- at considerable distance (> 1000 m)	7	5 - 10
- at medium distance (500 - 1000 m)	12	10 - 15
Village well		
walking distance < 250 m	20	15 - 25
Communal standpipe		
walking distance < 250 m	30	20 - 50
Yard connection		
(tap placed in house-yard)	40	20 - 80
House connection		
- single tap	50	30 - 60
- multiple tap	150	70 - 250

Figure 9-3. Domestic water consumption by service level: 7 to 150 lpcd

Hofkes (ed.) (1983)

In Figure 9-4, Morairty (2011) provides a matrix of five service level indicators for three African nations and India. In this conceptualization, access, quality, and reliability dimensions have been introduced, but the scalar water quantity dimension has been compressed into just a few minimum standards.

Indicator	Mozambique	Ghana	Burkina Faso	India
Access	**Distance** No norm[5] **Crowding** < 500 people	**Distance** < 500 m **Crowding** BH < 300 people W < 150 people SP < 300 people	**Distance** PS <1000 m SS <500 m **Crowding** SP < 300 people BP < 10 people PDC < 100 people BF < 1000 people	**Distance** < 1600m horizontal < 100m vertical (in hilly area) **Crowding** HP/SP < 250[6] people.[7] **Social exclusion**[8]
Quantity	20 lpcd	PS - 20 lpcd HC - 60 lpcd	PS - 20 lpcd HC - 40-60 lpcd	40 lpcd 70 lpcd (with high livestock density)
Quality	WHO guidelines	Ghana Standards	WHO guidelines	Bureau of Indian Standard (BIS Is:10500)
Reliability	Nothing defined	Rural – nothing defined SS % time available >95%	Nothing defined	Security concept[9] At least once in a day

BH – borehole, W – well, PS – point source, HC – house connection, HP – handpump, lpcd – litres per capita per day, SS – small system, SP – standpipe, BF – Borne Fountaine (a type of public standpipe), PDC - poste d'eau communautaire (a group of stand-pipes, each dedicated to one family).

Figure 9-4. Selection of service level norms in developing countries.

Morairty et al., 2011

Figure 7-3, shown on page 80, illustrates a per capita consumption quantity-to-travel-time relationship in graph form, with values from 50 lpcd for 2 minutes round trip time, following a curve to 9 lpcd for 45 minutes travel time. These numbers trace a course similar to other sources.

Service level consumption table

The following table is a composite, combining the previously displayed figures to provide a coherent and smoothed progression of approximate credible water consumption values.

Table 9-A. Service levels and water consumption

Service level	Type or characteristic of supply	H2O lpcd	Notes
No service or Inadequate service	Source >1000 m, and/or unprotected source, contaminated water, insufficient quantity, >30 minute collection time, crowding at source, unreliable delivery	<5	High level of health concern High caloric/time burden Economic costs associated lack of service
Boundary of adequate service	Source >1000 m, tap or handpump >24 minute collection time (per trip)	7	Water of adequate quality High caloric/time burden
Basic access 1	500 to 1000 m, tap or handpump 12 to 24 minute collection time	12	High caloric burden
Basic access 2	250 to 500 m, tap or handpump 6 to 12 minutes collection time	15	Moderate caloric burden
Basic access 3	100 to 250 m, tap or handpump 2.4 to 6 minute collection time	20	Moderate caloric burden
Basic access 4	<100 m, handpump, <250 persons per pump; 2.4 minute collection time	25	Assumes short wait times
Basic access 5	<100 m, tap, <250 persons per tap 2.4 minute collection time	30	Assumes short wait times Tap easier than handpump
Intermediate access 1	Private yard connection	45	Assumes minimal or no productive uses
Intermediate access 2	Single in-house connection	50	Generally kitchen tap; no productive uses
Intermediate access 3	Yard or kitchen tap with livestock/garden use allowed	70	Can be higher, productive uses creates open ended situation
High level service 1	Multiple in-house connections	150	Flush toilet + shower + limited or no outside use
High level sercice 2	Multiple in-house, with livestock/garden use	250	Can be higher, productive uses creates open ended situation

At the basic service level, distance (or travel time) is clearly the driver of consumption, with an inverse correlation. To quantify this relationship with a rough metric, we can use mid-point values for basic access 1 and 3 (750m and 175m); there is a distance difference of 575m against a consumption difference of eight liters; equivalent to a one liter reduction in consumption for every 72 meters of distance increase. Majuru, Jagals, and Hunter (2012), in a helpful mention within a study on water service reliability, have provided an empirical reference: The authors noted and documented a 5.19 lpcd fall in water consumption when a primary source became unavailable and users were required to travel 639 meters further, indicating a relationship of one lpcd reduction per 123 meters increased distance -- somewhat less effect than the composite table, but in the same direction and order of magnitude. Taking the average, a ballpark calculation reference could be “one liter less for every 100 meters more.” At the higher service levels, convenience, number and type of fixtures, and presumably the efficiency of the fixtures, appear to drive the consumption.

Service levels, water system cost, and consumption

Though specifics of water system capital costs can vary widely depending on the community where they are placed, the more elaborate infrastructure and the increased per capita water flow of higher service level water projects invariably cost more to build and operate. In Figure 10-5, Morairty and Butterworth (2003) provide an example in an African context of the relationship between service level, capital cost, and O&M costs.

Whatever the service level and characteristics under discussion for new water delivery projects, if there is no tether between project cost and contribution required from the benefitting population, the tendency is to solicit and advocate for the highest and most expensive service possible, even at the sacrifice of long term sustainability. As the previous figures and the table 9-A show, higher service levels are tightly linked to higher consumption. By extension then the lack of end-user copayment (or ‘counterpart contribution’ in NGOspeak, or ‘local match’ in munispeak) for infrastructure is also linkable to higher consumption levels, completely apart from the issues of water pricing, metering, and operational costs once the system is built.

Service level	Rural - hand pump	Rural/peri-urban - communal standpost	Urban - yard tank (low pressure)	Urban - roof tank (medium pressure)	Urban - piped water and house connection (full pressure)
Typical consumption (lpcd)	15-25	15-25	25	60	120
Capital cost in (€/household)	25	305	390	470	530
O&M costs in (€/household/month)	0.4	1.4	2	2.4	3.8

Figure 9-5. Comparative service level and cost scale in developing world setting

Moriarity and Butterworth, 2003, cited in Moriarity, 2011

Determining a generalizable numerical linkage between infrastructure co-pay by the end user and water consumption is not practical because each water system presents a different budget and each community has a different population and economic situation, but to some degree a meaningful co-pay requirement is a brake on aspirations for unsustainably high service levels and the higher water consumption. In this light the co-pay level could arguably be said to be a sustainability-inducing modifier of water consumption (though of difficult-to-determine weight), giving additional justification for demand assessment, WTP (willingness to pay) assessment, and meaningful local contribution to cost requirements, for all water projects.

Once built, with service level set, O&M will have an impact on consumption only if the O&M is reflected in the price of water and the water is metered, or the O&M expense is high enough that the water service fee rises to a price that impede subscription by some potential end-users. Generally water system designers seek to avoid exclusionary water service hookup or ongoing fees.

Water service level as health improvement leverage tool

People are generally highly motivated to get water or improve service for manifest health and/or convenience reasons, making it a potent tool to leverage other human improvement priorities like hygiene and sanitation. The characteristic of water service to be a carrot in community development and infrastructure projects, particularly sanitation and hygiene initiatives (e.g. Africa Ahead, 2011), may lead to situations where there are justifiable reasons to raise service level (and water consumption) other than the demand for water itself.

Intermittent vs 24/7 water systems

Intermittent service can knock an otherwise acceptable water system down to the bottom of, or completely off of, service level charts by affecting any of three dimensions of water service: quantity, quality, reliability. Interruptions to water service have an obvious but difficult-to-quantify impact on the quantity water consumption, as well as a less obvious impact on water quality and health. Reliability impact varies with the nature of the interruptions. There has been some treatment of intermittent service in the literature, e.g. Choe, Varley, and Bijlani (1996).

Water lost to leaks will be reduced proportionately with the time out-of-service, easing substantially system water losses and the water utility burden in leaky systems. End-user domestic consumption is also reduced, but not in a time-proportional way since interruptions create pent-up demand for when service returns. Countervailing factors may include increased tendency to leave taps open when service is interrupted and hoarding mentality when there is a perceived possibility that service will be interrupted.

The health impact of intermittent supply has been sometimes ignored or given only passing mention in literature treating water consumption issues. Where deficient water systems (such as those found in much of the world) face problems of limited supply, an intermittent delivery scheme may be unavoidable, either seasonally or year round. As noted in Walker & Velazquez (1999), developing world water systems can lose half of their water to leaky pipes. Limiting water delivery to a few hours a day saves tremendous quantities of water, but at the cost of depressurizing the system. While under pressure, the leaky system squirts water into the ground surrounding the pipes; when the system is shut down, contaminated water seeps back into the delivery pipes, to be dispensed at the next cycle. Health impact can also occur in cases of long interruptions, if per capita water consumption falls below minimums needed for hygiene, even if the water is not contaminated.

Reliability has two sub-dimensions. First is the unreliability of the system not providing continuous service. Second, if the periods of interruption are unpredictable, the inconvenience to the end-user is multiplied as planning for water access becomes difficult and unfulfilled travel to water points can occur.

The variables of and individual circumstances of intermittent supply make generalizable quantification of water consumption impact unfeasible. The health impacts make intermittent water delivery schemes undesirable. In any case, most water systems are not designed to be intermittent, so even the fact that it does effect consumption is not justification to adjust consumption expectations downward. Given the financial and non-financial costs associated with intermittent supply, it probably makes more sense to treat the condition as an aberration rather than a solution. Choe et al. and others have found ample evidence in WTP studies of capacity and willingness by end-users of intermittent systems to pay for continuous water delivery. As importantly, Choe et al. (1996) cited evidence of higher costs associated with coping with intermittent service than providing continuous service.

Water for health vs water for productive uses or gardens

Some service level scales include domestically-based productive uses at the upper end, and an example has been included here, Figure 10-6. When water is scarce water used by some for productive purposes has the potential to deny water for basic health to others. Highest and best use determinations, priorities, tradeoffs, differential pricing, and adequacy of supply can figure into this type of service level scale.

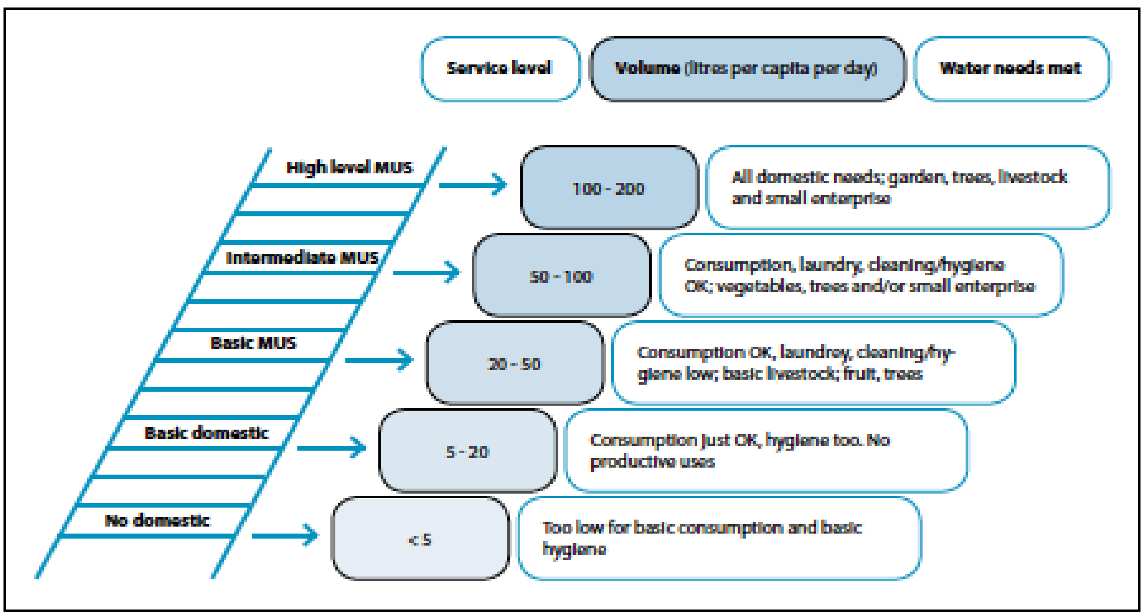


Figure 9-6. Scale of productive uses in an otherwise domestic setting

Renwick, M. (2007) in Moriarity (2011). MUS = multiple use [water] services

WHO data (2005) has listed the following ranges for productive water uses that may occur in the domestic context. Cattle/horses/mules: 20-30 liters per head; goats/sheep/pigs: 10-20 liters per head; chickens: 1-2 liters for 10 birds; vegetable gardens: 3-6 liters per meter. At a small scale, these amounts are not necessarily problematic for community water systems, and confer economic and nutritional benefits to families in a position to take advantage of the water resources. According to Renwick, 50-100 lpcd would cover this demand category.

Conclusions/action

-Service level concept can be represented by a single strand (e.g. public well → yard tap → kitchen tap → full indoor plumbing) or multi-dimensionally (e.g. factors of quality, quantity, reliability, distance/time to source, public/private, persons per water point, wait times, # of water using devices in home). Water consumption varies as a function of service level from 5 to 250 lpcd. For basic levels of service water consumption runs between 5 and 15 lpcd, intermediate levels 40 to 60 lpcd, and high levels are 150 lpcd and greater. Note composite Table 9-A, pg. 106, for a more complete list. Service level is a powerful modifier of water consumption.

-International, national, and local norms are notable for eschewing indication of service levels in water consumption stipulations, creating confusion. In norms, stating single design parameter water quantities is easy and common; discussion of different service levels may be logistically or politically fraught and is less common.

-Higher service levels have been linked closely to higher costs as well as higher water consumption. Where subsidies or outside investment occurs, lack of meaningful beneficiary co-pay of capital cost can lead to higher-than-sustainable water consumption.

-Water systems can function as leverage for other pro-social initiatives, especially sanitation and hygiene, possibly justifying higher water service levels than would be the case if the water service were considered in isolation.

-Intermittent water delivery is a wild card variable and does not generally appear on service level charts, though conceptually it is akin to a service level. It has an impact on three dimensions of water service: quantity, quality, and reliability. Given that water interruptions can contaminate water, it is not advisable to use intermittent service as a regular tool for water savings. Where systems provide only intermittent service because of deficiencies, it’s worth noting that the coping costs of intermittent service can be greater than the cost of providing 24 hour per day service.

-Productive uses of water in a domestic context can figure into the higher service levels. If held to a small scale, they can be quantified as adding 50-100 lpcd.

Chapter 10: Conservation technology and education

Introduction

Water conservation technology and conservation education could be considered conceptually and functionally very different modifiers of water consumption, but the best data on water conservation efforts come from work that includes combined ‘behavioral’ and ‘hardware’ approaches. As such, they are considered together here. Water conservation has yielded modest declines in per capita water consumption in wealthy nations, which are notable for high water consumption as a starting point. Water conservation is less discussed in the context of developing nations where per capita water consumption levels are already well below those of wealthy nations and where other limiting factors such as distance to the water source or the burden of water carriage serve as built-in conservation agents. In settings where water is not piped to the house, the issue of the water-saving fixtures – the hardware – is likewise not an issue. In very poor areas with limited access to water and consumption, the impetus can be as easily to increase water consumption as it is to conserve water.

Incremental improvements to existing technology.

Water fixtures and water-consuming devices have been the focus of intense, decades long efforts to reduce water use without compromising functionality or user comfort. Europe has long provided leading innovation in this area for washing machines and other devices. In the United States, the EPA, through its WaterSense program, has more recently established similar conservation oriented standards. Incremental reductions achieved for all major fixtures have been widely credited with contributing substantially to the gradual decline in per capita water consumption rates seen in modern urban settings (e.g. Rockaway 2011). While technology improvements do not appear capable of making dramatic drops in our water use, Rockaway, in an evaluation of 43 North American utilities, found a steady decline in per capita consumption: a “gradual erosion of water sales” amounting to 15 to 20% of total usage. This is mirrored by our own Anchorage, Alaska data which show a ~20% decline over an 18 year period (See figure 15-1; AWWU, 2012). This especially significant because Anchorage remains an unmetered system (now relatively unusual) so the consumption decline cannot be attributed to the rising price of water or rational economic behavior. The following figure (10-1) illustrates the across the board declines in water use by fixture for Denver, Colorado, 1999-2012.

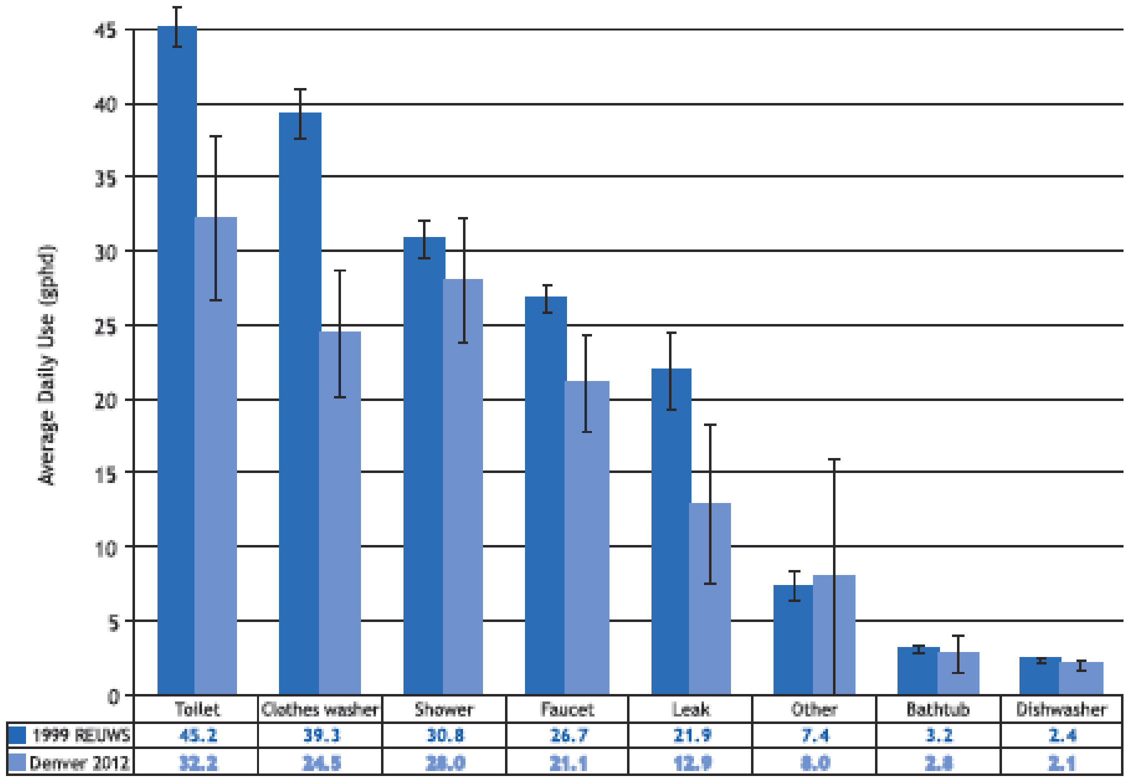


Figure 10-1. Water use changes by fixture, 1999 to 2012, Denver CO

AWWA Water Research Foundation (2012)

Affluent European countries, with their history of leading innovation in water saving in a modern urban context, provide some framing of what could be the lower boundary of per capita water consumption within the realm of conventional approaches. Aquaterra (2008) reported Germany's average domestic water consumption to be down to 126 lpcd, a number achieved through concerted water-saving efforts. Noteworthy is that involved parties informing the Germany section of the report believed there was little additional potential for further savings. Other water-saving leaders according to the Aquaterra report, were Belgium (107 lpcd), the Netherlands (127 lpcd), and Austria (~130 lpcd).

Finland, though not in the front ranks of low consumption countries, presented an encouraging case for wide spectrum conservation efforts in high water consumption countries. Aquaterra reported a decline in Finland from 350 lpcd in the 1970s to 150 lpcd currently. Rajala and Katco (2004, cited in Aquaterra) concluded that levels of 120 lpcd are achievable “with proper management”.

More recently, Vanham, Mekonnen, and Hoekstra (2013) indicated that water consumption numbers are continuing to ease downward across Europe, citing 114 lpcd as a 28 country European average.

Water use/conservation education

The impact of voluntary, pro-social, educational conservation efforts is an area of some interest in the sector, whether exploring options for meeting small community water needs in poor areas with limited access to water or the energy to pump it, or incrementally reducing demand in large utilities in wealthy cities in order to stretch existing supplies and defer infrastructure replacement.

The experience of this researcher is that water project and housing project implementers in developing world settings are generally enthusiastic, optimistic, pro-social educators and are inclined to believe that conservation education can reduce water consumption. Whatever the setting, the question of whether water use and conservation education actually has a long-term impact on water consumption levels is a matter of debate, however. Further, research around this modifier is somewhat susceptible to bias because the principles of resource conservation and pro-social action through education are both anchored in potentially passionate political orientations. It is also a challenge to parse the effect of conservation education from the more mechanical water-saving technology which often accompanies educational, marketing, or behavioral efforts.

In an extensive review of educational/informational campaigns to promote voluntary household water conservation (15,000 words, 88 refs.), Syme, Blair, and Seligman (2000) took up this question, noting that supporters of conservation campaigns claim important water savings, while critics counter that such campaigns are not cost effective, temporary rather than durable, and less suitable than other available options, e.g. pricing, use restrictions, or water-saving technological solutions. Syme et al. concluded that generally only small reductions in water consumption could be attributed to information and voluntary action. The qualitative review, using studies resulting from drought situations as the basis for much of the analysis, found support for estimating *short-term* water savings of between 10% and 25%, not a trivial number in an emergency such as a drought or a disaster situation. Where possible, the authors also subjected the data to regression analysis; noteworthy is that the regression based estimates "seem to indicate that campaigns have little success." Acknowledged problems with the regression analysis included co-occurring conservation measures such as water saving fixtures and other variables like water price increases, leading the authors to lean cautiously toward the more optimistic qualitative numbers in their conclusions regarding short term benefits. More significantly, however, for the purpose of this project, they conclude that a *long-term* reduction in water use *could not* be convincingly demonstrated from the conservation campaigns reviewed – thus making it doubtful to factor this modifier into long-term planning decisions.

For both the qualitative and the regression-based reviews, the effect of voluntary conservation in this study may have been distorted by looming non-voluntary restrictions that could be needed if the voluntary conservation failed to yield results. It is not certain that voluntary conservation in drought scenarios can truly be considered voluntary if the conservation is engaged to avoid harsher measures, and particularly if a range of harsher measures form part of a public debate. Additionally, conservation campaigns to 'get through a crisis' may be fundamentally different from and actually at odds with conservation efforts to inculcate permanent behavior change. Implicit in a drought-induced water shortage is the notion that someday the rain will come and 'everything can get back to normal'. This is antithetical to behavior change principles and the goal of long-term water conservation efforts. To rely on any data generated from voluntary conservation in drought or other emergency situations to predict water savings from similar efforts in non-emergency situations is arguably conceptually flawed.

In a recent experimental test of voluntary water conservation, Fielding, Spinks, Russell, McCrea, Stewart, et al. (2012) concluded that voluntary strategies do yield water savings initially (just under 10% of use), but that in "all cases, the reduction in water use resulting from the interventions eventually dissipated, with water consumption returning to pre-intervention level after approximately 12 months." This study was notable for its solid anchoring in behavior change theory, the use of multiple intervention techniques tracked individually along with an experiment control, and for following consumption patterns for more than a year.

The cited research focused exclusively on residential water service with modern indoor plumbing. For community water supplies with service levels one or more steps below those studied, it would be a reasonable assumption that the discretionary margin for reducing water use would be much less (and certainly no more) than the findings above. In small community public tap systems, personal restraints on consumption -- time spent travelling to water source and back or the effort of carrying water -- plausibly exert a natural water-saving force of greater impact than any voluntary conservation campaign. Additionally, educational/informational/behavioral water-saving efforts directed at individuals with already low per capita consumption may raise health issues (not to mention ethical concerns) if consumption is pushed too close to or below minimums established for basic hygiene and good health (e.g. Ritter, personal communication, 2012).

An Alaskan water conservation field note

Though in terms of households the numbers are extremely limited, and the generalizability of the environment as well, Troy Ritter (personal communication, 7 Feb 2014) reported that several isolated villages in rural northern Alaska have been documented with water consumption levels between 68 and 87 lpcd for fully plumbed systems, including flush toilets. Water consumption is by design limited to “six model healthy water use practices” – handwashing, bathing, household cleaning, laundry, drinking water, and human waste disposal. Water systems in this region are built in and on permafrost, meaning that the water must be heated and protected from freezing temperatures from capture, finishing, and delivery. Engineering the systems is complicated, energy inputs are extraordinarily high, and delivery is often precarious. In this context, awareness of the difficulty of obtaining liquid water is intuitive, and both economic and psychological pressures to conserve are substantial and constant. The harsh environment could arguably be exerting influence at the boundary between voluntary action and coercion. Toilet flushes are made generally only after defecation (not urination), and wash water for hands and for clothing is often reused. Ritter defined the 68 to 87 lpcd numbers as the lower threshold of [fully plumbed] consumption without impacting health. In any case the reported numbers represent a reference at the most conservative edge of consumption.

Experimental technologies.

There is no shortage of technological innovation aimed at reducing water use. Toilets in particular have been the focus of intense attention (e.g. the Dell Social Innovation Challenge, 2012), but it is relatively uncommon to see an innovation successfully enter the mainstream to the extent that it has a broad impact on water consumption. Classic barriers to diffusion -- cost, incompatible existing infrastructure, lack of disseminated knowledge of the innovation, and absence of opinion leaders -- impede innovation of water saving technology as effectively as other technologies. Those that can get over the diffusion barriers have the potential to make a water consumption impact, and their place in the collective imagination (of those in the water field) to modify water consumption is substantial.

In this investigation, a sampling of five innovations are briefly reviewed: in-home grey water reuse, dual water piping systems, improvement on the conventional composting latrine, desalination, and full wastewater recycling. These five were intended to give a sense of work beyond the incremental improvements to existing technology.

Residential greywater reuse. An example of this technology can come in the form of toilets that recharge the toilet tank by running domestic water first through a hand washing sinklet after each flush. See Figure 10-2.

Figure 10-2. Hand washing and flush tank refill -- simultaneously

Sinkpositive, 2013

The sinklet can be fit on most existing toilets with the faucet inlet attached to the existing refill tube, thus lowering existing infrastructure and cost barriers. Additional advantages are that the faucet dispenses water automatically after each flush -- allowing for hands free operation -- and providing both visual and auditory cues for hand washing behavior.

Disadvantages are that the sinklet cannot replace the conventional sink because it only operates when the toilet is flushed, and its location behind the toilet bowl is inconvenient to access except from the side (and many existing toilets are installed in narrow confines). Maximum water savings from the innovation would be at some point below the total bathroom sink water use, given that not all bathroom sink use would occur in the context of flushing the toilet (the sinklet only engages when toilet is flushed). If bathroom faucets draw 10% of total water demand, a plausible starting estimate could be 5% water savings until verified with empirical data.

More sophisticated systems channel grey water from bathtubs and showers through a processing station for toilet flushing reuse. The JetsonGreen Water Legacy is an example of a household water reconditioning and reuse system. The saving potential is high: if toilet water demand is completely met with grey water, savings could reach 25% of indoor water use. Cost, however, is a significant barrier (US$3200), as is the need for substantial replumbing work. Not all local codes allow for grey water reuse (personal communication, Patricia Butler, 26 December 2013).

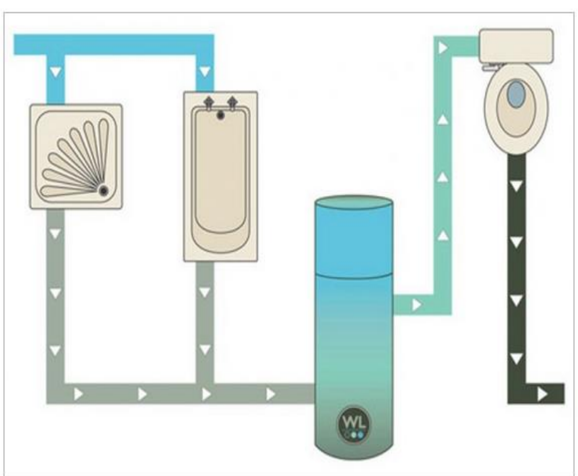


Figure 10-3. Water legacy grey water reuse schematic and grey water tank

JetsonGreen (2013)

DeOreo, one of the primary authors of the landmark Residential End Uses of Water Study (1999) and of multiple other water use studies -- and as such not likely to be swayed by the illusory promise of fashionable but unfeasible technologies – commented that “recapture and reuse of domestic water would provide a quantum increase in household water use efficiency”. He estimated that 80 lcpd of water savings could be achieved from successful implementation of domestic water reuse (2011).

The consequences of misalignment between water supply and real water need are not trivial. For example, it has recently come to light (as a result of water conserving technologies) that when overall water consumption is too far suppressed, sewer lines can become clogged because the water flowing in the pipes is not enough to move the solid waste,).

Extreme water savings can have negative consequences further downstream as well. Min and Yeats (2011), in describing the impact of water conservation efforts on wastewater treatment facilites (WWTFs), acknowledged that systems designed for non-water conserving communities have in the past experienced increased odor, solids settling, and clogging issues. San Francisco’s sewer system became overwhelmed by precisely too little wastewater as a result of water conservation initiatives (Smiley, Aug. 6, 2011). Min and Yeats did not characterize the increased proportion of total suspended solids (TSS) arriving to treatment facilities or other wastewater problems as insurmountable, but rather as a matter of adjustment to sewage system and WWTF design. However, if recycled water use were to achieve a “quantum increase” in water use efficiency, the issue could require closer attention.

Dual water supply systems have the potential to reduce use of highest quality freshwater in situations where it is extremely limited and a seawater source is easily available. Dual systems represent a considerable additional infrastructure investment in running parallel supply lines to every household connection, but they require minimal new technology and have been successfully implemented. Tang (2000) documented the case of Hong Kong, which must draw most of its domestic water from the neighboring Guangdong province in mainland China. Hong Kong (pop. 7 million), has run a dual water supply since the 1950’s. Seawater is used for toilet flushing and other non-potable needs, displacing about one quarter of the total water use.

Other aspects of dual systems (using seawater) are the cost of pumping water from sea level, the need for corrosion resistant pipe and fixtures, and sewage that is of high salinity. Tang indicates that the seawater component is not an impediment to sewage treatment, but it may affect its feasibility for reuse in agriculture (the system is dual only for water delivery, not the sewer).

Dual water systems with recycled wastewater rather than seawater have been experimented with in the western United States and other locations. In this mode, the recycled water, generally of potable quality though recycled from residential wastewater, is used for the residential outdoor water tap(s). In arid locations, where residential outdoor water use can reach 70% of the residential total (see Table 17-F), this constitutes a major water savings (personal communication, Patricia Butler, 26 December 2013).

Urine-separating composting toilet. The nemesis of dry composting toilets/latrines wherever they are employed is excess moisture from urine, which impedes the desired biological processes of decomposition and turns the waste matter soggy, sludgy, and smelly. Separating urine from the solids is a *sine qua non* for the typical composting latrine. Some are designed to shunt the urine to a separate drainage area, but have achieved only limited success. Separation is not easy -- urination and defecation frequently occur together and the spatial logistics of urine capture are different for men, women, and children. Some systems have used urine catch basins in the toilet bowl, but such system are impossible to optimize for both sexes simultaneously, and are prone to fecal matter clogging.

The Ojtitoilet is a potentially more functional composting toilet with a urine separation system that takes advantage of the adhesion property of water. Water based liquids, because of the adhesion property, will run down a vertical surface and turn an angle around a curved lip rather than fall straight off an edge (Ojitoilet). Note Figure 10-4, with a urine catchment ring at the bottom of the basin (cut-away view).

Figure 10-4. Urine diversion system toilet bowl

Otjitoilet.org (undated)

In this case when the urine runs down the side of the bowl it swings around the curved lip just enough to be diverted to the catchment ring, while simultaneously allowing solids to fall directly into the pit below. The urine is diverted through a tube to a gravel soakaway/leachfield.

A better functional composting latrine design holds the promise of permitting dry sanitation in situations that are not viable for rural pit latrines, e.g. peri-urban application. This would have the effect of reducing pressure/need to transition from dry sanitation to flush toilets in some settings. Quantification of the amount of water savings would be speculative, but whereever put into service it would have to result in some savings.

Desalination is a conceptually proven but still-maturing technology designed to take advantage of seawater or brackish waters, converting them to potable or higher level nonpotable freshwater uses. While it has enormous long-term potential given the abundance of seawater, its short and medium term expansion is hampered by poor cost competitiveness driven by the energy intensity and relative technological complexity of the current processes. (e.g. Younos, 2004). Desalination of seawater requires with current technology up to 16.5 kwh of energy per 1000 gallons according to Webber (2011), or ten to twelve times the energy needed for standard drinking water treatment (Gleick, 2008).

Desalination has developed in parallel with recycling of wastewater, which uses similar technology and in the future may be its main competitor. In a comparison of desalination to fully recycled wastewater (to potable standards) Dolincar and Schafer (2006) found the overall cost of desalination to be 2.2 times that of recycling wastewater. However, the authors noted that recycling of wastewater currently suffers from an exceedingly poor public perception while seawater is seen as more “pristine.” Regardless of the distasteful image of recycled wastewater, its use for residential water supply is on the horizon (personal communication Patricia Butler, 7 Dec 2013; Eleanor Allen, 29 Dec 2013).

Desalination requires with existing technology acidic compounds that must be disposed of after use, and a desalination by-product is a salt laden brine (Dolnicar &

Schafer). With the technology improving, however, desalination projects are occurring around the world, especially in places characterized by abundant and cheap energy resources, or by limited water supplies where the high cost can be justified. Desalination currently is often implemented as a supplement to existing supplies to help create a "diversified water supply portfolio" rather than as a stand-alone solution (e.g. Damitz, Furukawa, & Toal, 2006).

The long-term prospect for desalination does represent a potential game changer in meeting human water needs because of the abundance of seawater. Freshwater is just 2.5% of the total water on earth, and of that miniscule portion, most is unavailable for human use, locked in polar ice caps or beyond feasible extraction depth as ground water. No different than other areas water study, there is confusion and contradiction in the literature about exactly what small portion of the freshwater subtotal is actually available to humans. Some sources indicated that an amount just under 1% of *all* water, i.e. about 30% of freshwater, is available (e.g. World Wildlife Foundation [WWF], 2013; Dept. Natural Resources, Louisiana). Numerous other sources (e.g. UN Water) stated that less than 1% of *freshwater* is available to us, an amount two orders of magnitude smaller than the previously mentioned amount.

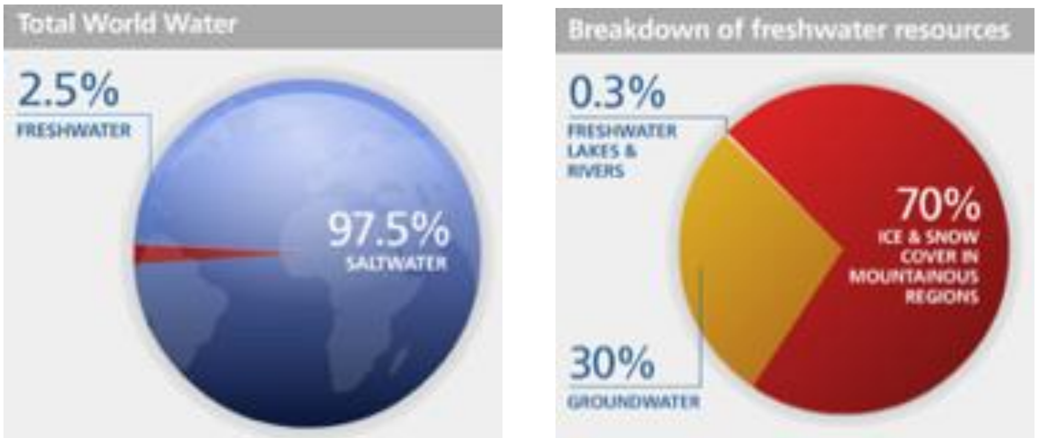


Figure 10-5. Saltwater and freshwater percentages of world water.

UN Water

The confusion is exacerbated by easily misinterpreted graphics and imprecise language. The above figure was found in UN Water's statistical information pages, and would appear to support the statement of "something less than 1% of *all* water, i.e. 30% of freshwater, is available", since the reader may assume that groundwater generally is available. However, the accompanying text outline concludes with "less than 1% of *freshwater* is available" statement, presumably because the extreme depth where a large portion of groundwater is found renders that water not practically available. In any case, even with the wide discrepancies in the literature, it could be said that for an energy input of one order of magnitude beyond our current level, somewhere between 2 and 4 orders of magnitude more water than is currently available could be opened up for human consumption.

It should be noted that the current energy inputs used to achieve desalination are approximately six times the theoretical limits of efficiency (Damitz, Furukawa, & Toal, 2006), leaving substantial room for further efficiency improvements. Additionally, desalination work is in its infancy; continued technology innovation and economy-of-scale improvements are reasonable expectations.

The availability of desalination, even if as a last resort, virtually guarantees that we can not run out of water in absolute terms, though the price we pay for it could be higher than our current comfort zone. Assuming a current payment of 2% of our household income is customary for water, a ten-fold increase in price with current desalination technology and energy input efficiency (as indicated by Gleick) would put desalinated water at 20% of household income with no adjustment to interacting factors. However, with a price increase of such size, market forces could be expected to exert tremendous demand side behavioral pressure on users to conserve water. Further, water conservation technologies could be expected yield additional water consumption savings with the high price of water driving both innovation and immediate adoption. Lastly, market pressures would be powerful to improve and cheapen desalination technologies and to reduce energy inputs per unit of water processed. If price driven market forces succeeded only in reducing demand by 25%, and technology improvements only reduced cost by 25%, and energy inputs were reduced by only 25% (all highly plausible in looking at the distance to theoretical limits, the stage of the technology, the power of market forces, and consumer behavior), then 75% of desalination cost could be driven out and the long-term equilibrium price could be brought within reach of the 5% rule.

Fully recycled wastewater. Using the same technology employed for desalination, wastewater can be treated to potable water standards, and at lower cost. In the case of seawater, removing dissolved solids (salt) by reverse osmosis is a large driver of the energy intensity of the overall process. Sewage, though it gives the impression of needing substantial effort to clean up, is very low in dissolved solids (suspended solids are another matter, but relatively speaking, easy to separate). Wastewater has generally no more than 1 gram per liter of TDS (total dissolved solids) where seawater is at 35 grams per liter or higher. While still an expensive process, at 45% of the cost of desalination, wastewater recycling has a hefty advantage in direct competition (Dolincar & Schafer, 2006). Other than losses that occur from ingestion, evaporation, and water system leaks, wastewater recycling can recapture virtually all of residential water used indoors. In an efficient water system leaks are less than 10% than the total delivered residential water, ingested water less than 1%, and evaporation presumably negligible. The outdoor component of residential consumption would not generally be available for recapture, however. Thus, in a system with a 25% outdoor water use component, wastewater recycling could be expected to recover just under three-quarters of the originally delivered water.

Conclusions/actions.

-Incremental improvements to existing technology (i.e. low-flow fixtures, improvements to water circulation efficiency in home) have been shown to yield a modest but sustained decline in water consumption, at the level of 15 to 20% of total use. In progressive European countries, water consumption has fallen to ~120 lpcd, largely attributable to reduced flow fixtures.

-Voluntary behavioral conservation efforts may be able to make a small contribution to water savings, but the evidence is less than irrefutable. Under non-distress circumstances the range of voluntary conservation efforts could be estimated from negligible on the order of 10% of total use. References to higher numbers in the literature could be the result of promotional bias in reporting, inadequate time frame of study to capture true long-term outcome, or unusual and/or poorly generalizable cases such as the threat of coercive measures looming behind voluntary restrictions. A cost-effectiveness evaluation of educational/information/campaign approaches vs. water saving technology investments would be highly recommendable before choosing the strategy.

-Voluntary conservation may have some application in emergency situations, with potential short-term savings up to 25% of normal use. In a modifier framework, water saving impact should be bounded by 0 to 10% of total. Rural Alaska provides some evidence of sustained use below normal patterns (68-87 lpcd), but the harsh environment could be argued to be exerting a constant coercive influence.

-Experimental technologies in some cases hold promise for water saving, but barriers exist to their large-scale adoption. Four examples are discussed in the section: grey water reuse, dual water piping systems, improvement on the conventional composting latrine, and desalination.

-Residential grey water reuse has the potential to shave 5% of consumption in the case of low-cost sink retrofits to toilets, and up to 25% in the case of more sophisticated systems (that require partial re-plumbing).

-Dual water systems based on seawater/freshwater supply can reduce demand on freshwater by approximately 25%, but require the infrastructure of two complete water delivery systems. Pumping must generally occur from sea level.

-Technology to effectively separate urine from solid waste is crucial for making the dry sanitation option of composting toilets more feasible. The Otjitoilet is one of a new generation of latrine/toilet innovations, which address the urine issue. The water consumption impact is from forestalling the need to transition from dry sanitation to flush toilets.

-Desalination holds ability to increase our available water supply by 2 to 4 orders of magnitude. The primary barriers to diffusion currently are extremely high energy inputs and complex technology required. Desalinated water costs approximately 10 times what convention water does to process. However, the current energy input is roughly six times the theoretical limit for the process, leaving substantial room for innovation. As technology improves and scale of implementation of desalination grows, desalination will be able to serve as a near infinite supply of ‘plan b’ water, with the restricting factor not the lack of water, but rather simply the willingness to pay the price for it.

-Wastewater recycling, using desalination technology but at 45% of the cost, is a competitive alternative where new freshwater sources are limited. Its acceptance is slowed by poor public perception about ‘drinking wastewater’.

Chapter 11: Wealth and water prices

Living standard or wealth

A well-founded expectation can exist in locales of large wealth disparity that the wealthy capture and use enormous quantities of water from common supplies, to the disadvantage of poor users. Certainly wealthy water consumers are better positioned to capitalize on available water for productive uses or to possess houses with larger yards and more water amenities than the poor. In North America, for example, the REUWS observed particularly high water consumption in the wealthiest community of the survey. Yet this researcher's experience in a developing world setting includes witnessing numerous cases where the very poorest users in some community water systems equal the rich in water use by leaving broken taps open with the professed inability to pay for a new tap, or aggressively usurping water for irrigation purposes, driven by the need to survive. Walker and Velasquez's data (1999) appeared to confirm the tendency for use to be high for the relatively poor urban areas studied.

Differences in patterns of consumption that vary with living standards may be obscured by aggregated data. For example, while wealthy users may have more access to sumptuous lavatories and a predisposition for large lawns, they also have access to the best water conservation technology, which is a countervailing influence. The modest water use patterns of northern Europe, with high service levels and the world's highest living standards (e.g. Aquaterra, 2008), are indicative of the challenges in making generalizable positive correlation statements about wealth and water use.

Even if a detectable relationship between wealth and water consumption could be demonstrated with appropriately disaggregated data, it is likely a distal variable mediated through other co-variables. Service level of water delivery (see chapter 10) appears to be a much more proximate variable, in particular with regard to the presence of indoor plumbing and flush toilets, which are linked to a leap in consumption. Lot size is another co-variable of wealth more directly linked to water consumption, especially as regards outside water use. Apart from the evidence that there are other more proximate variables to draw upon is the practical consideration that individual wealth is a difficult variable to work with. Income and/or wealth data is less observable or discoverable in public records than either lot size or water service level and wealth is a much more intrusive topic on which to gather information from participants. The REUWS, in facing this exact problem, chose to use house square footage as a surrogate for wealth. It is possible that authors made erred in choosing house size as their surrogate for reasons discussed in Chapter 13; however, they did acknowledge in the document the possibility of using lot size instead as a surrogate – which would have been a more defendable choice.

The practical impediments to accessing solid wealth/water relationship data, as well as the correlation distance between wealth and water compared to other potential variables, argue against its use as a water consumption modifier.

Price

Of all the potential modifiers of water consumption, price would seem to be among the most straightforward. A central tenant of capitalist economics is the utility of price as a tool to communicate scarcity and efficiently transfer or distribute goods and services. Surprisingly, however, price is of limited usefulness in modifying domestic water consumption for the following reason: Water is considered a fundamental human right, and as such, not entirely subject to the laws of supply and demand with price as the arbiter. Even in the circumstances where the water consumption of some persons is close to 100 fold more than others, the notion of the water consumption is sometimes seen broadly as a human right to be protected, and not only the small percentage that is physiologically essential.

Setting aside for a moment the human rights issue, price elasticity of demand information provides a practical measure of the power of price as a modifier. Demand elasticity for residential water has been subjected to study in a number of illuminating situations. First, the REUWS reported higher price elasticity for outdoor water use (-.82) compared to indoor, consistent with the belief that outdoor uses are more discretionary. Within indoor uses, toilet water use was the least elastic (-.15), shower and bath somewhat more elastic (-.35). The REUWS noted a wide range of water prices in the studied cities (from \$0.20 to \$1.32 per cubic meter) and indicated a moderate elasticity for overall consumption (-.49).

Staddon discussed the phenomenon of differential price elasticity, summarizing two studies that found that “average price elasticity was very low but highly variable -- more well-off residents exhibited no demand elasticity whilst poorer residents showed alarming levels” (Al Qdais and Al Nassay, 2001; Drozdov, 2002). This goes to the critical weakness of price as a tool to modify consumption: the power of price to rein in consumption is proportionately higher for the poor, resulting in a situation where the most vulnerable may suffer reduced access to a essential human need and determinant of health, while there is little impact on water consumption among the wealthy.

Concern about the detrimental effects on the poor of the proportionately higher price they pay for water was reflected in an EPA report (2002). It raised the question of whether the median U.S. income should be used as the base for deriving the figure of 2.5% of household income, which serves as the EPA determination of maximum acceptable cost for water service. The report makes much of the disproportionate nature of water fees regardless of the reference chosen. The authors appear to be inclined to consider a lower reference for the 2.5% figure, such as the 25^{th} percentile or the poverty-line income rather than median income.

Sometimes mentioned in the discussion of water pricing is the ‘5% rule’, a reference to a perceived need to hold the cost of residential water service to no more than 5% of the household budget (e.g. McPhail, 1993). Eskaf (2013), in crossing U.S. Census median household income (MHI) data for four cities with their average water utility bills, provided a picture of typical percent allocations from the household budget for water services. Israel (2006) found water service price of around 2% in Bolivia; McPhail noted prices up to 7% of hh income Morocco.

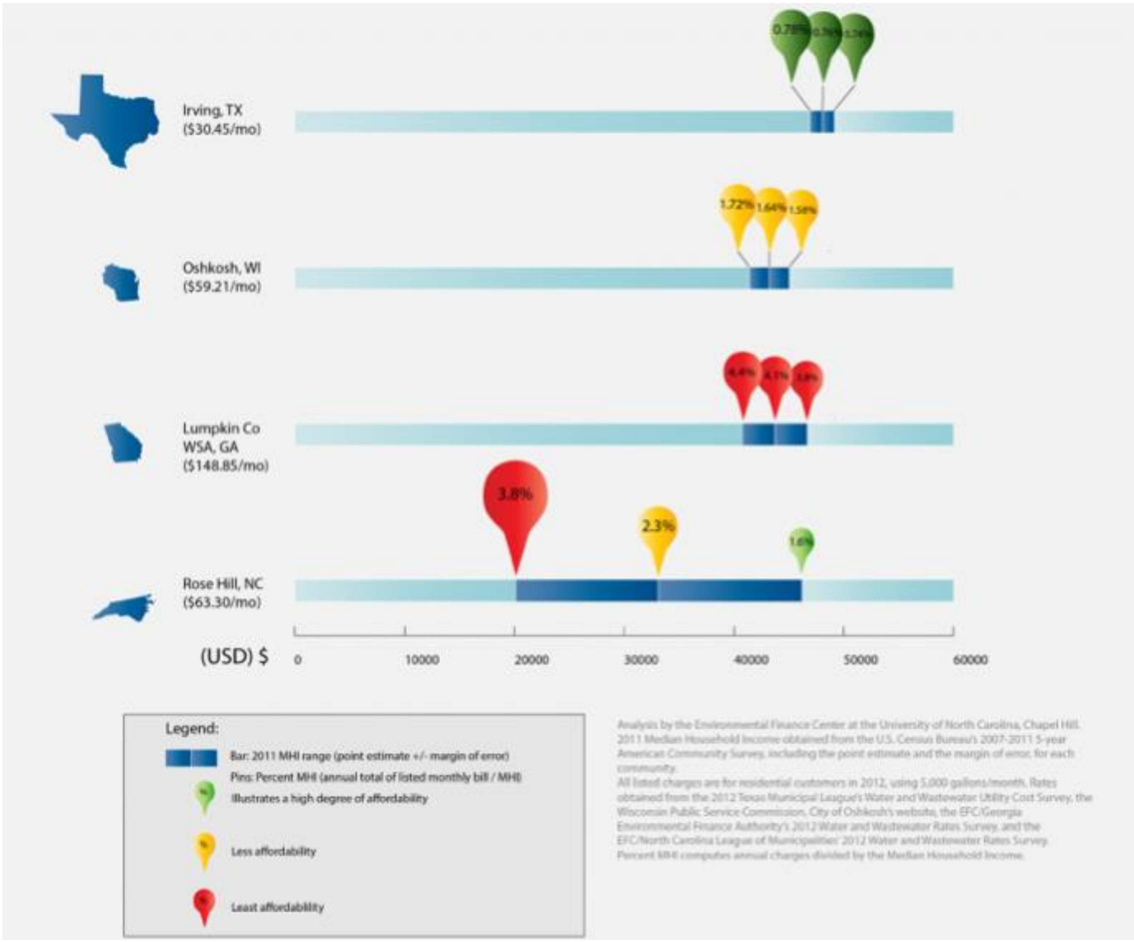


Figure 12-1. Residential water and wastewater as percent of income, 4 U.S. cities

Eskaf (2013)

The operating space of price as a tool to modify water consumption is limited against the backdrop of the societal need to provide a basic human rights water allotment without imposing price as a barrier -- even for the poorest persons -- along with the data that indicate that price has only a modest effect on the consumption of those with the ability to pay. Additionally, modification of water consumption through price is potentially a risky proposition from a utility policy perspective, where high prices to rein in consumption could be seen by the public as manipulation, profiteering, or price gouging.

The foregoing is not to indicate that charging for water is inappropriate, or even that prices shouldn't be high. Price is an effective tool for raising revenue, and the relative inelasticity of essential demand (i.e. toilet flushing) is, from a revenue perspective, an argument to set the price at full cost recovery levels. The caveat is only that those with limited income need access to a basic allotment of low cost water. Adjustments to accomplish this is in fact a common modality around the world, described as "increasing block pricing" or "lifeline tariffs", where a certain amount of water per month is made available at lower cost than subsequent blocks, or a minimum health-ensuring amount is made available at nominal cost. The approach is something of an anomaly in market economics where increased volume usually results in discounting – increasing block pricing with its discount for smaller volumes generally applies only to residential water connections. A review of the REUWS data showed a lower priced block (volume) of water available for most of the studied cities of around 450 lpcd on the average, a fairly generous allotment. In a developing world setting (El Salvador) Johnson (2003) noted around 100 lpcd to exceed the basic block price. The net result of increasing block prices is a progressive water price scheme, which serves to ease the burden of disproportionately high water bills for poorer end users.

Ironically, the flat fee structure, which is the traditional method of charging for domestic water and popular among those opposed to metering, is in fact highly regressive and anti-equity oriented.

Following is a tentative list of the functions and dysfunctions of price:

Cover water system O&M cost -- yes

Cover water system capital replacement -- yes

Cover system expansion -- yes

Restrain non-essential discretionary use -- yes

Restrain essential use -- no

Profit – no, or only to socially acceptable extent

Presented this way, it is possible to appreciate that the water consumption control is not at the core of the price mechanism functions.

Figure 12-1 provides an opportunity to see a number of countries' water prices, compared against domestic use numbers found in the second to last column. Noting only Denmark, at one extreme ($8.83) and India at the other ($0.15) and their similar consumption levels is sufficient to determine that a lockstep relation between consumption and price does not exist. Somewhat different domestic consumption numbers can be found in Figure 6-7 on pg 43, but they offer no clearer evidence of a strong relationship between consumption and price.

Average tariffs ($\$/m^3$) and water usage in selected major countries

Country	Combined tariff	Water tariff	Wastewater tariff	Change %	Domestic use l/head/day	No. of cities
Denmark	$8.83	$4.32	$4.52	0.1%	114	2
Australia	$5.78	$3.14	$2.65	11.5%	605	5
Germany	$5.36	$3.33	$2.02	1.8%	151	10
France	$4.56	$3.24	$1.31	-0.6%	232	7
United Kingdom	$4.27	$2.07	$2.19	3.9%	139	8
Czech Republic	$3.63	$1.86	$1.78	5.7%	213	3
Canada	$3.14	$1.95	$1.19	7.5%	778	5
Poland	$3.12	$1.44	$1.68	17.8%	149	6
United States	$2.98	$1.29	$1.69	8.1%	616	27
Japan	$2.56	$1.48	$1.08	0.2%	373	13
Portugal	$2.27	$1.62	$0.65	0.6%	308	3
Spain	$2.13	$1.47	$0.66	1.9%	342	6
Turkey	$2.14	$1.38	$0.76	10.5%	238	8
Italy	$1.81	$0.94	$0.87	11.6%	483	6
Russia	$1.00	$0.61	$0.39	21.9%	368	13
South Korea	$0.76	$0.56	$0.20	0.2%	552	7
Mexico	$0.69	$0.65	$0.04	2.8%	200	11
China	$0.46	$0.34	$0.12	5.7%	95	25
India	$0.15	$0.14	$0.01	1.8%	139	17

Figure 12-2. Snapshot of water price data.

Zetland (2011)

Low level equilibrium traps (LLETs) warrant brief mention because they can suppress water demand by holding the service level lower than what it would otherwise be; hence they technically are modifiers of water consumption. In the classic form an LLET occurs when a community or user group rejects the established price for water service because of previous or expected future poor service, resulting in continued deficient service because of lack of resources, for which the community or group refuses to pay. This creates a vicious circle and ensures a service level below what the group in question desires and would pay if it could be broken. Whether labeled as such or not, LLETs are a common occurrence in developing world settings. Numerous willingness to pay WTP studies have indicated a trapped demand for better service (e.g. Hensher et al., 2005; Gunatilake et al., 2007; WB, 1999; Littlefair, K., 1998), though disagreement exists over the reliability over the primary valuation method, contingent valuation, for quantifying the demand.

Conclusions/action

-The linkage between wealth and water consumption is likely a distal variable; more proximate and hence more appropriate linkages to water consumption are residential lot size or service level. Because wealth data is private information, it is also a suboptimal choice as a modifier of water consumption for practical reasons.

- Price is constrained as a modifier of water consumption because of inherent conflict with the notion of water as a basic human right. Price elasticity of demand is moderate or minimal for the wealthy, yet ‘alarming’ for the poor. The use of price to restrict basic levels of water use is not considered consistent with social goals. To counteract the disproportionate burden of water price on the poor, the standard tool is the ‘increasing block tariff structure’.

-Flat fees for water service, though ostensibly the friend of the poor, are regressive and may not capture adequate revenue for system sustainability.

-Though price can modify consumption, more important functions of price are operating and capital costs of the water system.

Chapter 12: Dwelling size

Intuitive notions around dwelling size and water

Do occupants of larger houses use more water? From time to time the assumption surfaces that bigger houses mean more water use. It is possibly bundled in with conclusions drawn about the bigger yards in which bigger houses often sit, or possibly derived from a general sense that the often wealthy occupants of a big house simply must consume more water in the same way they likely consume more of other goods. In unmetered rural community water systems, the thinking behind such commentary can be that owners of bigger houses should pay more for their water. Response to these notions is difficult because of the lack of solid data on the question disaggregated from other potentially causal variables. In the absence of good data, the ‘feel’ that the dwelling into which water is piped influences the actual consumption can gain traction. The analysis here indicates that dwelling size is in fact not reliably linked to water consumption, with the following details provided to adequately counter the perception that it is.

Intuitively, a larger house requires at least some additional water compared to a smaller house, for cleaning if nothing else, but the lot size on which the house sits and the number of occupants in the dwelling appear to be tightly bound co-variables of greater importance than dwelling size (discussed in chapters 14 and 15). Even at the most generous estimate, domestic cleaning is not as large a component of domestic water use as ‘occupant load sensitive’ activities like bathing and human waste disposal (toilet flushing), or of voluminous outside water use for lawn, garden, or domestic animals (e.g. EPA, 2008). Also wrapped into the question of dwelling size is the variable of occupant wealth, with dwelling size potentially linked to two divergent trends. A obvious driver of dwelling size is indeed wealth, presumably positively correlated. However, larger dwellings can also be a function of family size, which is linked to poverty and simultaneously to the previously mentioned co-variable of number occupants in the dwelling. The backdrop is then of two ‘difficult to control for co-variables’ (lot size, occupant load) with ‘difficult-to-separate’ trends that could obscure a dwelling-water relationship, and of at least one additional co-variable (wealth), where the linkages could mutually cancel out evidence of a relationship between size and consumption. Given that backdrop, the goal of this section is to rationally frame and to attempt to place credible boundaries on the maximum impact that dwelling size could have on water use, so that unaddressed conjecture or doubt about the issue doesn’t undermine discussions, calculations, conclusions, and decisions.

Framing how much the house uses

Numerous educational and technical websites provided household water consumption breakdowns; oft repeated EPA data on the topic, which appeared to be derived from the landmark Residential End Use Water Study, or REUWS (1999), was well representative of the categories and quantities in a developed world (U.S.) setting.

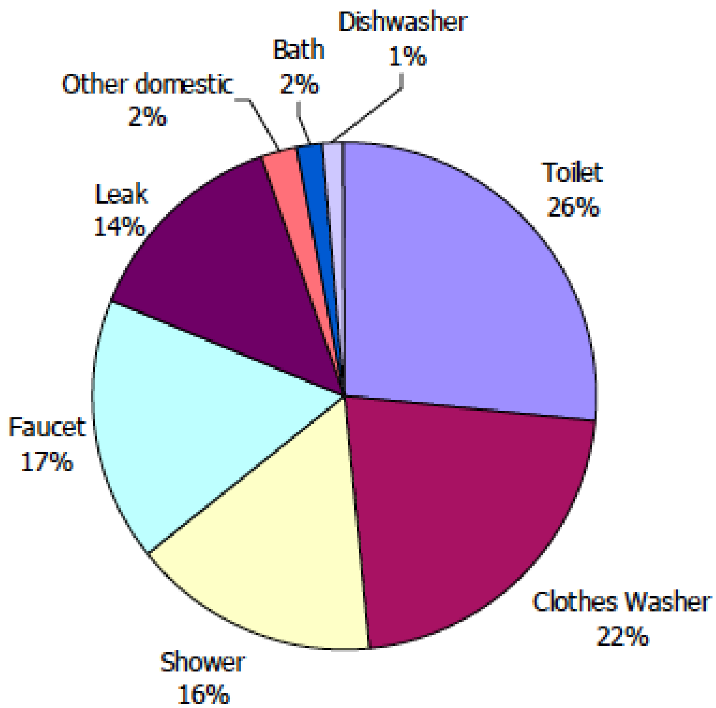


Figure 13-1. A breakdown of indoor domestic water use in the U.S.

REUWS (1999) as reported by EPA (2008)

In the breakdown, the distinctly individual drivers of water consumption that are not a function of house size but rather the individual occupant -- toilet, shower, clothes washer, bath, and dishwasher -- accounted for 67% of indoor consumption. The general categories of *faucet use (17%)* and minimal *other domestic (2%)* come to 19%. Within the 19%, any conceived 'dwelling size driven use' for interior cleaning would be shared with at least five substantial individual or 'per capita driven' uses: drinking, hand and face washing, tooth brushing, cooking, and hand dishwashing. In the displayed breakdown *leaks* account for an additional 14%, which for our purposes can be distributed among the other functions as a byproduct of or consequence of use. By allocating this use proportionally among all the intentional use categories (adding 11% to individual functions and 3% to mixed individual and house related functions), we can attribute 78% of indoor use (67% + 11%) to strictly individual functions and 22% to mixed individual and house related functions (19% + 3%). It is difficult to imagine the interior house-cleaning use rising to the consumption level of any of the other faucet and other domestic uses mentioned, but by granting parity to enable an outside (maximum) estimate we can see that it would still be less than 4% of the indoor total (taking 22% divided among six uses).

Outdoor residential water use varied widely by location, and is usually separated from the indoor uses in calculations (see Table 17-F, based on REUWS data and it's 2012 update). In arid climates with unrestricted water availability and year round watering needs (wants), outside use can exceed all indoor uses, i.e. adding up to greater than half of total domestic use. Even in wet climates with seasons of non-use, the outdoor component contributed at a minimum approximately 25% on top of total indoor use (more treatment of this water use is covered in chapter 15 on climate and lot/compound size). Taking into account even the minimum outdoor amount, this yields a likely total dwelling cleaning component that would be 3% or less of total domestic use, rendering any potential differences in water consumption based on a *variation* in house size to be of little import for overall use planning and decision-making.

The previous paragraphs permit a de-weighting of the dwelling-size-dependent contribution to water consumption but does not address whether there actually is a relationship or not. Approaching the question from other directions appears to point to the same net result of little or no influence, and even to an inverse relationship between water consumption and dwelling size. Two examples have been provided here. First, stand-alone rural home water supply and wastewater disposal systems serve as an excellent reference point for gauging accumulated sanitary engineering field experience regarding consumption patterns. Putting more water through these stand-alone systems than they are able to handle can lead to detectable, unpleasant, and health-threatening failures on the waste side (sewer backups). This is not viewed by homeowners, contractors, sanitarians, or any other persons affected as a desirable state of affairs: understandably, regulations regarding their sizing are considered important and carefully elaborated. In Alaska, as well as other jurisdictions, septic tank sizes and drain field sizes are stipulated by regulation based on the *number of bedrooms* in the dwelling (a proxy for number of occupants) rather than the *size* of dwelling (e.g. Inspectapedia, 2011; Alaska Dept. of Env. Conservation 18 AAC 72), giving a clear signal that from a functional engineering perspective dwelling size is not considered a reliable or meaningful driver of consumption, while maximum occupant load in the dwelling is what counts.

Second, Rockaway et al. (2011), in a macro-analysis of water consumption at 43 U.S. utilities, highlighted a gentle yet widespread phenomenon of decline in per household residential water use, amounting to approximately 15% of total use over a 31-year period between 1975 and 2006, or about half a percent per year. This tendency was also visible in Anchorage Water and Wastewater Utility (AWWU) data compiled from 1992 forward (Billman & Mullane, 2011). Though consumption bounces around from year to year, a trend line applied to the spreadsheet data showed a decline of approximately 10% in per capita water consumption over the past 18 years. In other affluent nations, Aquaterra (2008) reported domestic per capita water consumption declines of 22% in Denmark (1989-1998), 7% in the Netherlands (1995-2007), and 14% in Germany (1990-2004).

With the exception of a slight dip after the bursting of the U.S. housing bubble in 2008, data on dwelling sizes did not show any parallel decrease but rather a steady *increase* over the past three and a half decades. U.S. Census data (2010) revealed that between 1973 and 2010 the median square footage of new single-family construction has increased 42%, from 1525 to 2169 ft^2 (142 m^2 to 202 m^2). Overlaying the downward trend in water consumption with the upward trend in house size reveals that *on a per square foot of dwelling basis*, water consumption has actually decreased by nearly half in just three decades, a powerful inverse correlation. Because the home size data was only for new structures, the trend covering all existing housing would be more muted, though the direction of correlation would remain the same (in the same way an upward swing in incidence affects overall prevalence with a shift in the same direction but of less magnitude). Even as these data eviscerate the notion that a bigger house in and of itself requires more water, there is no apparent reason to conclude that making a *bigger* house would drive lower water consumption. Applying the razor, the simplest explanation is that the two phenomena are not directly related and other variables hidden behind house size are involved. Interestingly, research done for the California Homebuilders Association (ConSol, 2010) indicated that the *age* of the house is a large factor in consumption. According to their report, a post-2000 house uses on average only 64% of what a pre-60s house uses. In any case, these data point to impact from water efficient fixtures increasingly used in newer construction.

Year Built	Number of Units	Avg. Indoor Water Use	Avg. Outdoor Water Use
pre 60s	2,392,460	92,118	115,088
60s	1,143,459	92,118	115,088
70s	1,162,924	92,118	115,088
80s	1,135,153	74,306	115,088
90s	826,346	59,115	115,088
00s	889,181	59,115	115,088
Total	7,549,523		

Figure 13-2. Much larger houses, much less indoor water use.

California Homebuilder Foundation, ConSol (2010)

The number of occupants of the house as the driver of water consumption fits the data much better than the size of the house. Citing US Census 2000 data, Information Please tables (2007) showed that from the 1970s forward the average number of occupants per dwelling had fallen, even as house size has increased, and *along a trend line that mirrors the decline in household water use*. The US Census data indicates that in 1970 the median household occupancy was 3.14 persons. As of 2004, it had fallen to 2.57, a decline of approximately 18%. Rockaway, in discussing the modest but sustained and widespread decline in water consumption per household, mentioned the smaller household along with water pricing trends and diffusion of low-flow appliances as likely factors behind the trend.

Why dwelling size needs attention as a modifier

The data appeared to indicate that 1) dwelling size is not linked convincingly to water consumption, and 2) that even if a link did exist it would be of minimal weight in any consumption equation. A number of other co-occurring variables (increasing prices, increasing use of meters, increasing use of low-flow fixtures, increasing use of water-efficient appliances, increasing conservation awareness, and/or decreasing household occupancy) are all more likely drivers of water consumption. Though the evidence appeared weak for a meaningful dwelling size to water consumption positive correlation, the issue cannot be simply ignored. *Water use trends in North America* by Rockaway et al. (2011) provided a good example of how natural and persistent is the vague notion of house size somehow being tied by association to water consumption, even among experts on the topic. In their introduction, the authors framed their research in part with the following:

> It is clear, however, that the old rules of thumb [regarding water consumption] . . . are no longer sufficient. New water use predictions must take into account a variety of factors that may drive water use either up or down. For example, fewer people per housing unit or more water-conserving appliances in the housing market lead to less water use per household. Rising incomes, *larger homes* [italics added], and more landscaping, however, lead to increases in household water use (p. 77).

In their article they cited carefully collected and analyzed data from dozens of urban environments that indeed might support the idea that extensive landscaping could be linked to increased water use, but nothing but evidence to the contrary regarding dwelling size (and income for that matter). It was as if the dwelling and its increasing size were a symbol for a general concept of increasing consumption even as the article was largely focused on widespread per household declines in water consumption. The specifics of the article provided no support for their conjecture about a dwelling size to consumption link.

The REUWS, a widely known document in water circles, also made mention of dwelling size to water use link, in stating that “outdoor [water] use displays a relatively strong and positive relationship with home square footage”. The authors attribute the correlation to a link between larger homes, higher standard of living, and higher ability to pay for discretionary water use. Hasenyager, Adams, and Klotz (2010) reported a positive relationship between home floor space and indoor water use. They found a 19% difference between houses of more than 3000 sq ft against those of less than 1000 sq feet. Given contrary other evidence, this linkage is probably misleading: for the middle class homes of the REUWS sample, the larger homes likely sat on larger residential lots, and the lot size offers a much better explanation of the increased use, particularly outdoor use. Further, the authors of the REUWS noted the positive correlation of outdoor water use to lot size. Regarding indoor water use, in the face of enduring national scope increases in house size and simultaneous enduring national scope declines in water use, findings should be discounted or attributed to other variables occurring between very large and very small homes.

Conclusion/action:

-Dwelling size was either a negligible factor or possibly negatively correlated to water consumption with no convincing line of causality and should not enter calculations/matrices/scales for human water consumption. Because of widespread perceptions of possible (positive) linkages however, justification for its non-inclusion needs to be explored and substantiated. Occupants of the dwelling, the recency or efficiency of the installed water fixtures, or country in which the dwelling is located are manifestly more important dwelling-related drivers. The number of bedrooms or beds in the dwelling, or age of the structure, may be useful proxy/surrogate measures if direct measures are unavailable.

Chapter 13: Household size

Per capita vs per household

The most common unit of calculation or allocation of domestic water is by the person (per capita -- lcpd), but the household is also a prominent measure (lhpd), given that piped water schemes do not deliver water to individuals but to households. Water use in the household (in particular indoor use) increases as expected with each additional occupant, but it does not follow a linear path of a strict per capita relationship. Because the household water use is not entirely driven by the per capita equation, a brief discussion of the effect of household size on water consumption is warranted here.

The authors of the REUWS (Mayer, DeOreo, Opitz, Kiefer, Davis, Dzieglelewski, and Nelson, 1999), documented a gentle decline in per capita use as household size increased from 1 through 8 persons.

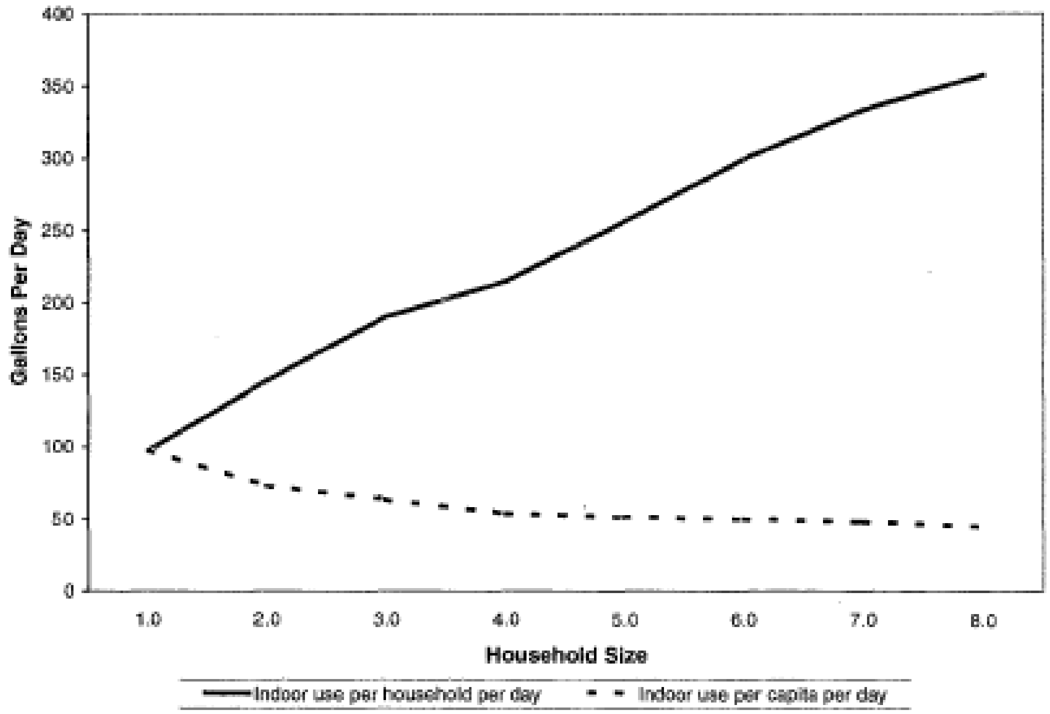


Figure 14-1. Household size and per capita consumption.

REUWS, 1999

Figure 7-3, it is shows that indoor use for a one-person household in the study was roughly 100 gallons (~378 liters), yet a three-person household was less than 200 gallons (756 liters) – rather than the expected 300 gallons. In the REUWS, the authors provided a lineal approximation to the curve tracing the marginal decrease in per capita indoor consumption.

$y = 37.2x + 69.2$

where y = indoor hh use; x = hh size

By the equation, the increased consumption was only 37.2 gallons for each additional person (141 liters), after a threshold consumption of 69.2 gallons (262 liters). The average per capita consumption derived from the same REUWS data however was

69.3 gallons (265 liters), a fairly substantial per capita difference. For the average size household of the study (2.71 persons per household), both calculations should yield the similar results in terms of total indoor household use

$$172 = 37.2(2.71) + 69.2$$

$$188 = 69.3(2.71)$$

The eight percent difference here could be attributed to the imperfect fit of a linear equation to an exponential curve. Larger errors in estimates or projections could occur if the population in question included a wide range of household sizes or the range was characterized by high variability.

DeOreo, in a similar water consumption study undertaken in five areas of Jordan (2011), documented a similar decline in per capita consumption as household size increases. Reanalyzed data from the REUWS was used for comparison (Figure 7-4, light and dark blue lines).

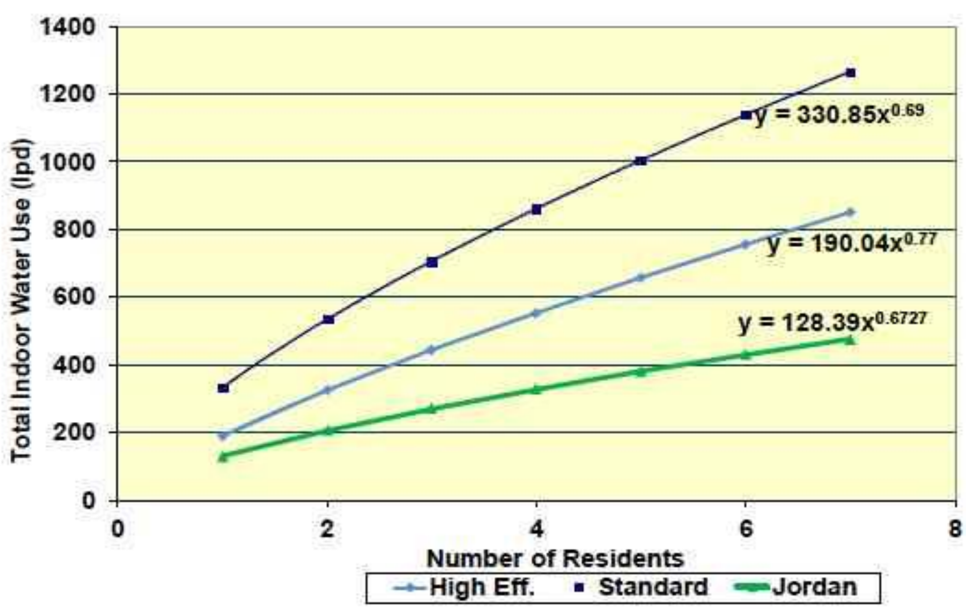
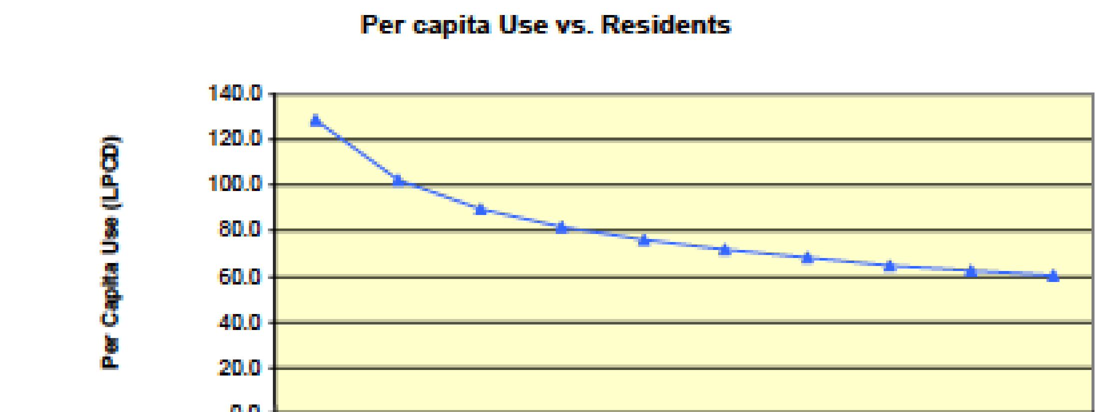


Figure 14-2. Household size and overall consumption curves

DeOreo, 2011

In the later Jordan study DeOreo stressed the non-linear relationship between household use and number of occupants and used power equations to present both the Jordan and reworked REUWS data. He suggests a 0.7 power relationship applied to per capita numbers as a reference. In figure 14-3 there is a decline in per capita consumption from 128 lpcd for a single person to 76 lpcd within a five-person household, again a substantial change. Marginal change is also pronounced. Marginal lpcd for the fifth household member is just 53 lpd.



	1	2	3	4	5	6	7	8	9	10
Norm. Per Capita Use	128.4	102.3	89.6	81.6	75.8	71.4	67.9	65.0	62.5	60.4

Figure 14-3. Household size and declining per capita consumption

DeOreo, 2011

Hasenyager, Klotz, and Adams, writing for the Utah Department of Natural Resources (2010), corroborated DeOreo’s work, though with somewhat different equations. More generally, Zhang and Brown also noted an inverse relationship between per capita use and hh size. Possible reasons given for the declining per capita use with increased household size are increased efficiency from washing machines and dishwashers more likely running full loads, or more children in the per capita count in larger households.

The above calculations were based on the indoor consumption component of water use, presumably because the indoor use is the most ‘per capita sensitive’ and outdoor use is stable (or changes little) with increases in occupants. Including the oudoor component of water use in the power curve would accentuate the power function (greater departure from 1, in this case a smaller number such as 0.5 instead of 0.7). An adjustment may be necessary to De Oreo’s 0.7 power if water consumption data is not broken down by indoor and outdoor use or appears to include the outdoor component.

Conclusions/actions

-Household size was inversely correlated to per capita water consumption. A 0.7 power relationship applied to per capita numbers in household provided a rough metric for quantification.

-As an example, in a study of consumption patterns in Jordan, the first person of a household consumed 128 lpd, the second added 77 lpd, and the fifth 53 lpd. The per capita numbers would be 128, 102, and 86 lpcd, respectively.

-Comparison of relatively homogenous populations is not seriously affected, but comparison of consumption could be compromised in the case of a developing world city (with an average hh of ~5) with an otherwise similar European city (with an average hh of ~2.5).

-Consumption and household size research was concentrated on indoor consumption, and does not provide insight on whether more people in the household drives an increase in outdoor consumption. In moist climates this is of little importance; in arid climates it could be very important.

Chapter 14: Lot or compound size and climate

Outdoor use in general

Residential lots/compounds/parcels lend themselves to substantial water use. In developed world settings it can be for amenities: lawns, ornamental plantings, and kitchen gardens. In rural or developing world settings it may be water-intensive home food production: vegetable gardens, fruit trees, chickens, ducks, pigs or other productive and subsistence uses. Quantification and management of this use component is critical to correctly sized and equitable water distribution schemes.

Taking a North American perspective first, in temperate climates with four seasons, outdoor (on the lot) water use patterns are easily discernable in the extant data. With a well-defined lawn growing season it is possible to see when the outdoor tap comes into play, and from that to approximate the total indoor and outdoor consumption. Anchorage, Alaska, in particular, provided a differentiated picture of yard use, given that the winter temperatures completely preclude opening outdoor taps (Anchorage Waster and Wastewater Utility, 2012). The Anchorage data also provided a view of an unfettered use pattern because of its current unmetered flat rate for most residential use. AWWU residential water use data reported for an Anchorage master plan update (2012) revealed a 10-year average use pattern in January to be 51% of peak summer use. The decline in per household use over time that is reported in other municipal water supplies by Rockaway et al. (2011) was discernable here as well. In the case of Anchorage's unmetered water supply it is worth noting that the decline is occurring only for the indoor use. Also noteworthy in the Anchorage data is the volatility visible in the outdoor component due year-to-year variations in summer weather, a harbinger of high sensitivity to broad climate change.

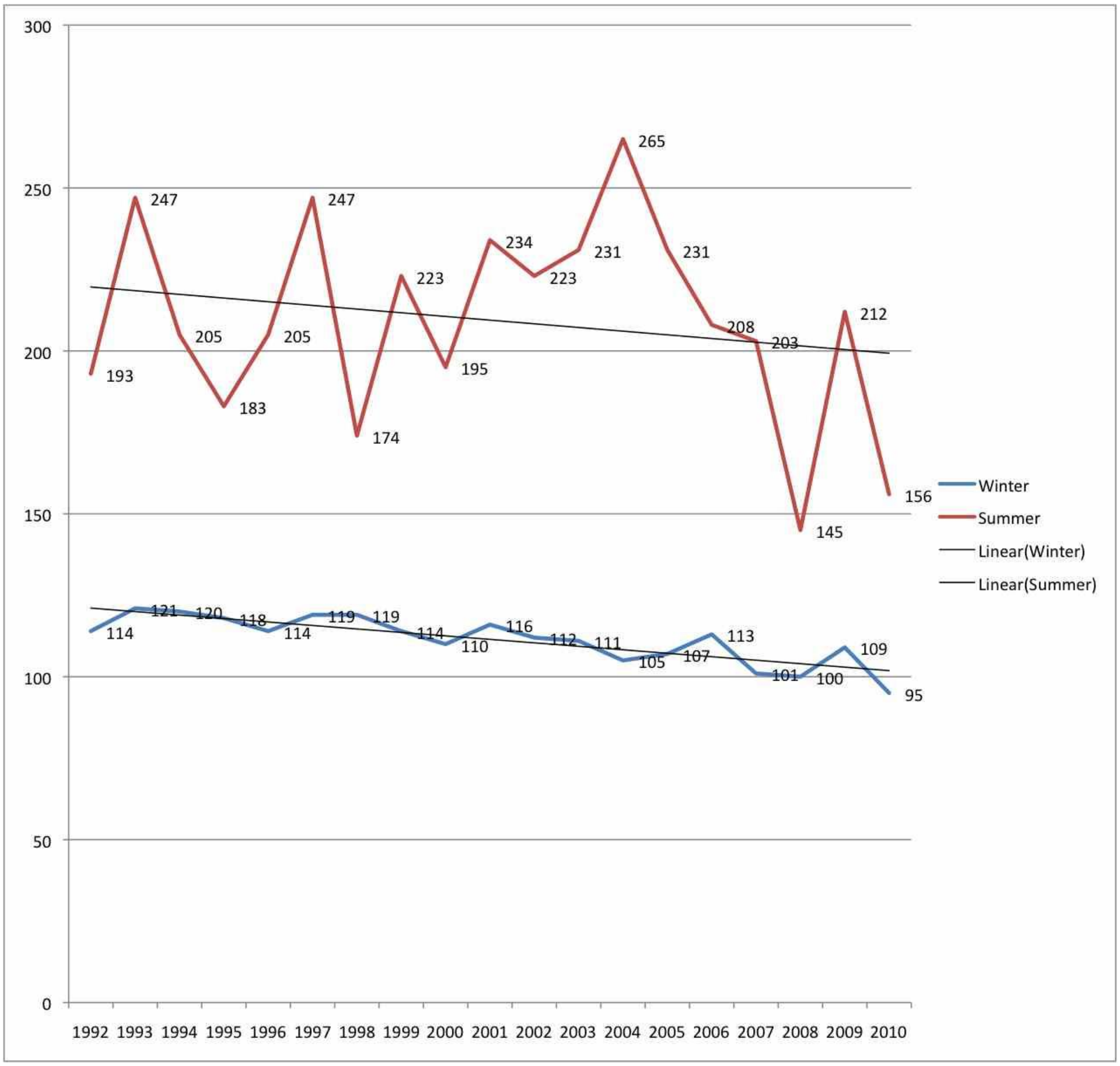


Figure 15-1. Anchorage winter to peak summer residential water use 1992-2010

Billman & Mullane, AWWU Master Plan update (2012)

Data available in a convenient form from another city, Newport OR, a temperate and non-arid location, also showed an approximate doubling in residential water consumption for summer months (City of Newport, 2007). The data were broken down in such a way that it was possible to easily estimate the outdoor contribution to total consumption. The ‘double use’ period is consistently about 2 months long with a month or so shoulder on each side; combining the shoulders we have the equivalent of approximately 3 months per year of double consumption. Reading the data points provided these spikes contribute approximately 25% to the total water consumption annually, consistent with figures from other sources for non-arid temperate climates.

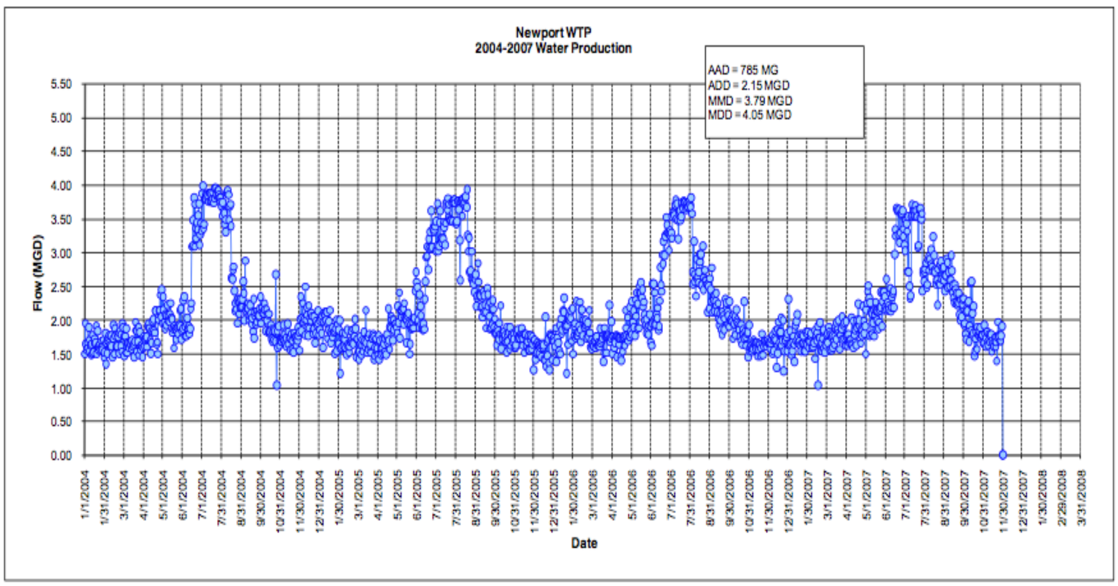


Figure 15-2. Summer lawn watering and seasonal variation

City of Newport, OR master plan (2007)

Data from the U.S. as a whole, which includes areas of year-round outdoor watering potential, showed a substantially higher outdoor use than the cases above, indicating that outdoor use can actually exceed the indoor use (REUWS, 1999).

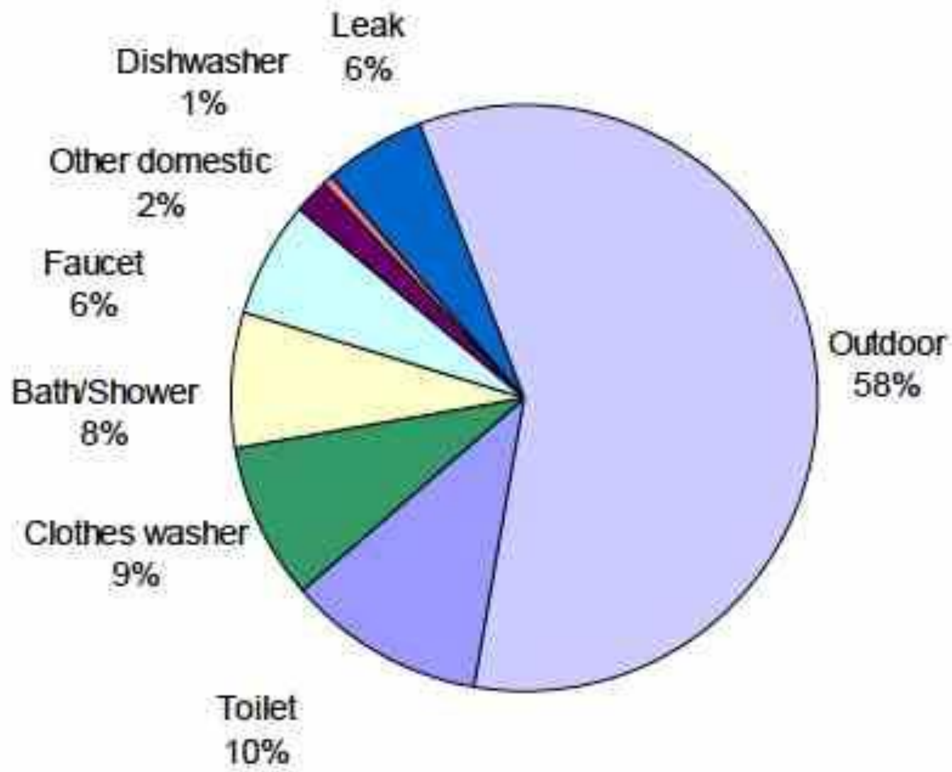


Figure 15-3. Breakdown of U.S. residential water use including outdoor component

REUWS (1999)

From data like Figure 7-4, it's clear that the land space occupied by water users presents special challenges to determining overall per person water use. Unlike the dwelling structure, which can essentially be minimized out of the water equation, the lot is a driver of a huge piece of the pie in many locales. Complicating the goal of reliable *per capita* consumption figures, a residential lawn requires the same water quantity whether there are 8 family members living on the lot or only one, and certainly it only takes one person to set a lawn sprinkler to work. Given this situation, a hybrid form of deriving use estimates might be in order, with a portion of water use driven by per capita calculation, and a portion driven by the household connection itself (as a proxy for lot or compound). This in essence occurs when data and standards are specified on a per connection basis. An estimate can be made about the average number of home occupants, which drives the indoor water use. This subtotal can be added to the outdoor use number, which is less a function of the number of persons and more of the lot.

Contrasting the U.S. data, a study from Sydney, Australia, with a progressive water savings program, presented what might help bracket the range of consumption in modern urban settings (NSW, 2003). There, though in an arid climate, the outdoor component of water consumption was only 25% of the total, similar to U.S. figures for wet temperate locations. This would indicate there is some wiggle room on the outdoor component, and that the individual locale circumstances play some role, but a ~25% add-on for the outdoor use may be a useful default lower-end value.

In terms of size, the classic urban standard for a U.S. city lot is ~7000 sq ft (50 feet by 150 feet, sometimes with ten feet shaved for alley easement, and designed to fit a 300 x 300 ft square, the standard city block). As an example, single-family residence (SFR) lots in Anchorage are established under municipal code as a minimum of 6000 sq ft (540m2). In a notably compact city like San Francisco, however, lots of half that size are not unusual. Many other North American cities have relatively large lot sizes, and from the 1950s to the end of the century local zoning in the U.S. routinely limited the dwelling structures to one per lot. Currently progressive urban trends are to increase density through 'compact housing' approaches (e.g. Municipality of Anchorage, 2012), and/or to permit a secondary dwelling on the traditional SFR lot as cities work to create higher density, yet appealing, living spaces in already built up areas (e.g. Seattle). These trends effectively enable cutting lot size in half on a per structure basis. Given the large component of water use attributable to the area outside the dwelling, reducing lot size could in turn arguably yield water savings and drive a downward slope of per capita water consumption.

Residential lot size as driver of outdoor use

It appears, however, that the reality may be more complicated than simply a matter of x volume of water per square foot of outdoor residential space. In the *Residential End Use Water Survey* REUWS (Mayer, DeOreo, Opitz, Kiefer, Davis, & Dziegielewski, 1999), a lengthy section is devoted to outdoor water use; data on lot sizes and building footprints were gathered. Within the REUWS, the interest in the lot size and footprint was only to be able to determine the net outdoor area, which when combined with local evapotranspiration (ET) data, permitted estimates of the efficiency of homeowner watering. There was no attention given to the actual size of the outdoor space, and with justification: for the 12 distinct cities studied, the ET appeared as a much more potent predictor of water use. Particularly surprising was data from two cities in a near identical location: Phoenix and Scottsdale, AZ. The ET is essentially the same, and so is the average outdoor water use, even though according to the table the irrigable area of an average lot in Phoenix is nearly twice that of one in Scottsdale.

It’s clear that having a lot or compound surrounding a dwelling creates a context for an outdoor water use component, but the extent of that use may depend in part on a human-to-greenery relationship that could be less defined by the square footage of the space and more by a desire or need for water. The data make more sense if the watering is viewed from the optic that watering serves a human therapeutic function, which is less linear than strict irrigation requirements or square footage.

Within any urban setting, the portion of that population that lives in stand-alone residences vs. apartments is a necessary datum to accurately gauge outdoor residential water use for a given population. Some studies (e.g. Aquaterra, 2008) indicated the availability of SFR vs. multi-unit dwellings data, but it is unlikely that such data is consistently available.

Outdoor use and price of water

Price has some effect on outdoor water use. According to Mayer et al. in the REUWS, outdoor water use does appear to be more elastic than indoor use. The price of water would presumably be able to exert influence on outdoor consumption patterns, particularly discretionary ones, though the evidence is ambivalent about whether this truly is an effective brake on consumption in affluent nations. An argument was made by Syme, Nancarrow, and Seligman (2000), based on a thorough look at the literature, that water is at least for now too cheap to drive behavior very much; restrictions on watering with social pressures (neighbors' vigilance), or conservation measures such as dry landscaping initiatives may actually exert more modifying influence. Full discussion of the limitations of price as a modifier of water consumption can be found in Chapter 12.

Climate as a driver of water use

This is a well-studied relationship, expressed generally through the variables of temperature and precipitation, and/or evapotranspiration (ET). It is possible to derive an outdoor water use correlation with climate variables. However, since we can neither control climate nor predict it (beyond a few days of meteorological phenomena), precise correlation formulas are of limited usefulness in the context of this investigation project. Such linkage could be valuable for a farmer who could then more accurately determine how much irrigation is needed for a given crop and then activate pumps or open sluice gates accordingly. In a domestic use setting, water system infrastructure and reserves need simply to be adequately prepared for the highest use scenario when it arrives.

Zhang and Brown (2005) have summarized well the general and unsurprising contours of the relationship of climate to water consumption: use per residence is inversely correlated with rainfall and positively correlated with temperature, as would be expected wherever part of the demand is from outdoor use. They also cited evidence of positive correlation with lot size. Like others, they note that indoor domestic water demand is inelastic, but peak summer demand shows higher elasticity, indicating the more recreational or at least discretionary nature of outdoor use

In reviewing data from a collection of North American cities representing distinct climates in Figure 15-4, it’s easy to see how challenging it could be to sort meaningful climate relationships beyond some very general determinations. We can clearly affirm that rainy cities have lower outdoor use than arid ones (e.g. Seattle vs. Tempe), cooler cities generally have lower use than warmer ones (e.g. Seattle vs. Tampa, and Denver vs. Phoenix), and cool, wet cities will have lowest use, while hot, arid, cities generally the highest. Note, however, that the very highest use was found for an area characterized by unusually large lots sizes (Las Virgenes Municipal Water District), indicating that climate does not necessarily predominate over the modifier of lot size.

Study site	Sample size	Outdoor Annual Use (kgal/home)	Indoor Annual Use (kgal/home)	Total Annual use (kgal/home)
Waterloo	37	7.8	67.7	75.5
Cambridge	58	7.8	71.2	79.0
Tampa	99	30.5	56.1	86.6
Lompoc	100	43.5	62.1	105.6
Seattle	99	21.7	54.1	75.8
Eugene	98	48.8	65.1	113.9
Denver	99	104.7	61.9	166.6
Walnut Valley WD	99	114.8	76.3	191.1
Boulder	100	73.6	54.4	128.0
Tempe	40	100.3	65.2	165.5
Las Virgenes MWD	100	213.2	70.9	284.1
Scottsdale	59	156.5	60.1	216.6
Phoenix	100	161.9	70.8	232.7
San Diego	100	99.3	55.3	154.6

Figure 15-4. Outdoor to indoor water use across l4 locations

REUWS (1999)

To assign values to the groupings, dividing the cities into four categories of cool moist, warm moist, cooler arid, hot arid, the following rough numbers can be derived:

Cool moist climate: outdoor use ~25% of total use

Warm moist climate: outdoor use ~35% of total use

Cool arid climate: outdoor use ~60% of total use

Hot arid climate: outdoor use ~70% of total use

The overall REUWS calculation of outdoor to total water use was 58%. Because the total use number varied widely along with its outdoor component, a stable indoor reference may be superior for practical quantification of modifiers. The following percentages come from using an indoor baseline reference of 225 lpcd:

Cool moist climate: outdoor use ~33% above indoor use

Warm moist climate: outdoor use ~55% above indoor use

Cool arid climate: outdoor use ~150% above indoor use

Hot arid climate: outdoor use ~230% above indoor use

Temperature was also indicated as an influencing factor in human intake (e.g. Gleick 1996), but intake was actually only a small component of total use. Other categories of indoor water use, such as clothes washing, may increase in warmer climates, but the literature did not highlight significant differences here.

In many jurisdictions, exact data is available for precipitation, temperature, evapotranspiration rates, population, and residential water consumption, making it tempting to develop precise formulas tying consumption to climatic conditions. Evapotranspiration (ET) rates for any given local would seem to be the most accurate way to predict/estimate outdoor use. However, this would likely be a case of spurious precision. Unquantifiables, such as changing cultural expectations regarding outdoor water use, restrictions on watering, incentives for dry landscaping, changing urban densities, changing ratios of multiunit to freestanding single-unit dwellings, and water pricing, would introduce other variables that make exact numbers less meaningful. In particular, the sprinkling of a green lawn should be seen as a cultural artifact mutable over time rather than a permanent water use component central to human wellbeing. In a more resource conscious, technology oriented, urban and less agrarian-referential world, the green lawn represents an emblematic but fading Veblen good. Rockaway et al. (2011) were explicit in mentioning that the “old rules no longer apply” for residential water consumption calculations.

The REUWS provided ET rates for most of the study cities. It was possible to see a relationship in the data; compare outdoor use of Figure 15-4 against ET of 15-5. The REUWS authors were reluctant to draw inferences from ET – outdoor water use data. It is true that high resolution uses, such as creating a mechanical linkage with a specific coefficient connecting ET to water use, would likely go beyond what the data could support. However, for low-resolution inference, this data is entirely suitable and shows that a relationship between ET and outdoor use exists.

Location	Seasonal ET (Apr-Oct)	Cooling degree days*		Max temperature		Total precipitation	
		Period 1	Period 2	Period 1	Period 2	Period 1	Period 2
Boulder	46.0	4.06	15.11	66.88	75.25	3.87	1.43
Denver	42.4	46.84	0.00	84.14	58.03	0.95	0.07
Eugene	29.7	18.24	0.00	80.48	47.08	0.02	5.27
Las Virgenes	39.2	202.36	0.00	91.06	55.47	0.01	11.84
Lompoc	29.9	52.01	0.00	82.61	66.51	0.00	0.27
Phoenix	58.6	188.29	6.74	96.36	74.23	0.00	0.08
San Diego	28.2	124.15	1.13	85.09	69.51	0.00	0.35
Scottsdale	58.8	181.04	0.00	94.56	63.80	0.00	0.63
Seattle	29.5	69.92	0.00	80.26	45.47	0.25	3.02
Tampa	38.2	140.90	99.30	82.97	82.49	2.62	0.55
Walnut Valley	39.3	233.61	8.42	97.33	72.06	0.00	4.07
Waterloo	29.5	49.73	0.79	77.48	62.38	0.55	0.15

Figure 15-5. Evapotranspiration rates (ET) across twelve cities

REUWS (1999)

A safe quantification would be that high ET areas are going to see “upper end” outdoor use profiles (e.g. Scottsdale) and low ET areas “lower end” use (e.g. Seattle). A simple correlation analysis of ET and outdoor use for the cities where data was available for both, yielded a correlation of r=0.64. This confirmed a relationship, but is far short of a mechanical relationship by which estimates of water use could be made, with additional obvious confounding factors including locally varying restrictions on outdoor water use, configuration of block pricing schedules, existence of programs for residential conversion to dry landscaping, and changing weather patterns.

Conclusion/action

- The lot or compound size drives a substantial yet highly variable component of water consumption. Larger lot sizes will result in higher consumption than comparable smaller lots, and higher proportion of families living on single family lots will mean higher per capita consumption compared to situations with a higher proportion of families living in multiunit dwellings.

-Climate also drives a large component of water consumption, specifically the outdoor component, which is tied to lot size. In a U.S. context, a plausible climate driven range of total residential consumption attributable to outdoor use is from ~25% in cool moist climates to ~70% in hot arid climates. As a proportion of indoor consumption with 225 lpcd as baseline reference the range is ~33% to ~230%.

- Evapotranspiration data is probably not adequate to alone create estimates of outdoor water consumption levels, but potentially could be an aid in conjunction with site specific data on outdoor water use policies and restrictions, general climate characteristics, typical residential lot sizes, and water pricing structure.

Chapter 15: Altitude within system and water line pressure

Water pressure and flow

Pressure variation is grouped with altitude differences because water pressure is a direct and linear function of vertical fall or rise (or 'head', in engineerspeak). In modern water systems, control valves exist in the distribution lines to ensure delivery of water to individual homes within a narrow pressure band, usually 40 to 60 PSI, effectively counterbalancing the wide differences in water pressure that would otherwise exist. For water systems that are small, rural, in poor countries, in hilly terrain, or with a combination of the above circumstances, altitude plays a large role in determining what pressure a family might have at their water tap, or whether water makes it to the tap at all.

At the level of physical characteristics in the behavior of water, pressure has a significant impact on flow rates in water systems through pipes and water taps. It also has a critical role in protecting water quality in the web of pipes that form the water system: positive pressure ensures that any leaks push water out of the system, but when pressure is lost contaminants from soil surrounding the pipes leak in reverse. Though a sensitive issue from both public health and engineering perspectives, it is not unheard of for someone to inquire about reducing water pressure as a way to save water.

Over the range of customary water pressures used to distribute water for domestic and commercial consumption, the formula of *flow varies by the square root of the pressure differential* can be used. Thus a doubling in the line pressure will increase the flow through a tap by ~41%, halving the pressure reduces flow by ~29% (in appropriately pipe sized distribution systems, the countervailing change in friction head losses resulting from the increased or decreased flow rate is not a large factor (at least over the range of normal flows and pressure changes contemplated) and they are ignored for this calculation).

Framing the link between flow and consumption

Presumably then, since flow varies with pressure, overall water consumption could then also vary with water pressure, though not with the simplicity and mathematical precision of the flow rate through an open tap, nor to the same extent. In some cases, such as in taking a shower, brushing teeth, or washing dishes, a lower pressure may result in reduced water use, because the person showering, brushing or washing might accept the reduced flow without changing behavior. In other cases, say filling a bucket or drawing a bath, the reduced flow may only prompt the user to leave the tap open longer to accomplish the desired task.

Given that some consumption categories will be subject to compensating behavior by end users, while other categories will not, the range of water savings resulting from a halving of water pressure would then be bounded by $0\%<x<29\%$. In some circumstances, 'halving the pressure' is a plausible action. For example, it could mean going from 80PSI to 40PSI: the higher number is an example of a residential maximum standard in the U.S. and the lower a widely used minimum acceptable pressure (e.g. Mass. Uniform State Plumbing Code, 2012; Uniform Plumbing Code 608.2). The above numbers established approximate boundaries for the range of plausible pressure change and the effect of that change on water consumption. In practice, an intentional change in water pressure is unlikely to be so dramatic as a halving, and compensating behavior is likely to further blunt the effect of any reduced flow achieved. Taking the case of mid-points for each dimension, reducing pressure by one quarter (instead of halving) would reduce flow by just over 13%; further, if half of water consumption is subject to compensating behavior, the net savings would then be on the order of 7%. This constitutes a rational framing of the range of the potential change.

The Environmental Protection Agency, in its water related public information (2010), citee a comparison study conducted in Denver, Colorado, illustrating with empirical data the effect of water pressure on water consumption. Denver presented an apt location for such a study: with pressure in distribution systems affected by altitude differences, in this hilly city some homes receive their water at appreciably lower pressure than others. Though the specific or average pressure differential was not in the citation, the homes with lower water pressure were reported to consume 6% less water annually. No mention was made of potential confounds, or of any efforts to control for them, e.g. homes at higher elevations perhaps having smaller lots/families (or the opposite). Additional corroborating evidence of presumed water savings can be found in the literature of vendors of pressure reducing valves, where water savings of 25% or more were claimed (e.g. Bugfish, 2011). These latter claims could be imagined to be biased by the commercial interests behind the claims, yet as indicated by the calculations of flow change boundaries, have some basis in fact. The convergence of the Denver study empirical data and the math based mid-point calculated values support a water savings default estimate at 6% or 7%.

A final implicit indication that waters savings does indeed result from reduced line pressure is that the EPA, in its WaterSense program, which specifies conservation oriented flow rates for toilets, faucets, and showerheads, also specifies a maximum service pressure of 60 psi.

Within a modern non-leaking water system, the effect of pressure reduction would necessarily be less pronounced than in the case of leaky systems found in much of the developing world; indeed, water pressure reductions (down to 0 PSI) are both a practical consequence of extensive leaks and a typical strategy for dealing with them.

Walker and Velasquez (1999) pegged unaccounted-for water in developing world systems at 50% for those reviewed. In such a system the unaccounted-for water flow would be reduced by close to 29% in the case of halving the water pressure (no compensating behavior on that portion of total flow assuming that the unaccounted-for water is lost to leaks), while the 6% figure may better reflect the reduction for the properly delivered water. Under this scenario, the reduction from halving pressure in a leaky system could be estimated by taking the average of the two figures, since each reality covers approximately 50% of the system's water. Thus water flow savings in a leaky system would be calculated to be (29 + 6) /2 =~ 17%. A one-quarter pressure reduction would translate to ~10% reduced consumption.

When water pressure is reduced in a planned manner across a water distribution system, the potential exists then, both by empirical evidence and by calculation, for a modest water savings. However, water pressure reductions, where some or all users' water pressure falls below a certain threshold (ex. 7 PSI), risk creating undesirable water consumption restriction, contamination risk (from a health perspective), and water access disparities (from health and social perspectives). A field example of the altitude/pressure issue: the village housing project that prompted this investigation was designed in such a way that a few of the houses built at one end of the project at a slightly higher altitude made equitable water delivery substantially more complicated and increased the water system cost in a desperately poor community. The few houses in question could easily have been built in an alternative location (since this was a new housing project). It is unlikely that any of the infrastructure professionals involved with the housing project were aware of the impact on the water supply resulting from decisions made about where to site the houses.

Water distribution networks are not naturally uniform in supplying water – inequities in line pressure and actual water delivery are common in small systems built with limited resources. Houses located closer to a water source or at lower altitude than others can in certain conditions have better access to water, particularly in situations where water is scarce, systems are overextended, or where supply is intermittent.

Conclusion/action

-Water pressure is a valid modifier of water consumption, with the likely range of water savings at 6% to 10% from a normal range pressure reduction. Pressure disparities or pressures below an adequate flow threshold risk health and social consequences that should be weighed against either lowering pressure to save water, or accepting wide pressure variations in water system design to save money.

Chapter 16: Traditional sources and improved water supplies

Scenarios when new water source becomes available

In a developing world context, access to a traditional unimproved water supply such as a spring or river after a new public supply has been built (for example a well with hand pump) can influence water consumption levels or even acceptance of the new supply. (e.g. Moriarty, Batchelor, Fonseca, Klutse, Naafs, et al., 2011). This is plausible particularly if the time needed to travel to the new supply is similar to the traditional source or the new water supply comes at a perceived high cost (e.g. Mu, Whittington, & Briscoe, 1990; Engel, Iskandarani, & Useche, 2005). An example can be where users make limited use of a new well and pump – perhaps using it primarily or only for drinking and cooking water while continuing to use a traditional source for bathing and clothes washing (e.g. Tompkins, 2013). On the other hand, where the ‘taste or trust’ of the new water differs (unfavorably) from that of the traditional source, and the new water is close at hand, the users may take advantage of the improved water for its convenience to do washing, cleaning, cooking, and personal hygiene, while continuing to draw small quantities from the traditional source for drinking. This has been noted to occur in Alaska Bush communities (Troy Ritter, personal communication, 2011). Both scenarios could distort empirical data on water consumption for a new system. In either scenario, a preference for traditional sources may also be simply a matter of previously established custom, subject to migration to the new source following a classic innovation adoption curve (Rogers, 1963).

It is worth noting that distance/time comparisons between sources for estimating relative convenience may be deceptive. For example, with public supplies, clothes washing residents may opt to carry clothing to be washed say 200 meters to a traditional source rather than lug washing water (at a weight of a kilo per liter) even 100 meters from a new source. Alternatively, residents may opt to wash or bath right at the dispensing point. Sometimes communities decide to not permit bathing or washing at the new supply site to avoid congestion or excessive drainage water accumulation. All these permutations can affect the relative use of the new source vs. the traditional source.

In wealthier nation urban settings the issue of traditional sources interference is less relevant. Water is generally supplied by a single source or provider, and standard ‘piped into the house’ water connections are considered a pre-condition of residential occupancy. Traditional sources (even if available) do not seriously challenge this level of service (Mu, Whittington, & Briscoe, 1990).

WHO data (2005), within the context of a minimal water supply situation, broke down a 15 lpcd allocation into 5 liters for drinking and cooking, and 10 liters for laundry and hygiene (for 20 lpcd, the respective breakdown in 7 liters and 13 liters). If the traditional source is retained for clothes washing and bathing, then a reduction in the anticipated consumption from the improved source could be up to two-thirds. If the traditional source is retained only for drinking and cooking water, then the volume reduction will no more than one-third.

Trust of users in the water supply and water quality

User perceptions about the healthfulness of a particular water supply can vary widely. Lack of trust in a water supply could result in unusually low consumption figures, as nominal users continue to rely on or return to traditional or secondary sources. This may be tied to real and perceived water quality, turbidity, and availability of traditional or secondary water source options.

Conclusion/action

-For newly constructed improved water supplies that are at a service level lower than a tap in the yard or water piped into the house (i.e. a public dispensing point of some sort) and where a traditional source is easily available, continued traditional source use may cause measured new supply water use figures to be below design estimated figures.

-If the traditional source is retained for clothes washing and bathing, anticipate up to two thirds reduction; for drink and cooking, one third; drinking only, one fifth.

-Though a traditional source that provides water of similar convenience may retain a certain loyal following for after inauguration of the new source, caution should be used in making water supply planning or design decisions that depend on contribution from the traditional source. Even with multi-year observations, use may eventually migrate to the new supply.

-Reducing comparative distance from a new supply to home or increasing the service level to that of yard tap or in house connections is the most reliable way to ensure complete adoption of new source if that is the desired goal for public health reasons. The need to charge a sustaining price for this service may constitute an obstacle to this goal.

-Water source decisions are most sensitive to collection time, price, and perceived quality. Distance may be used as a proxy for time: 1000m equivalent to 24 minutes, based on round trip time calculation and 5kph or 3.1 mph average speed, though waiting time may need to be factored in if dispensing point serves more than 100 users.

Chapter 17: Results

The data found in the foregoing chapters on individual modifiers (7 through 16) are presented here in distilled form. Some of the data lend themselves best to display in brief narratives, others in tables. The tables are designed to give in a single eyespan as complete an illustration of concepts as possible. After the tables is a collection of data use scenarios by potential stakeholders mentioned in Chapter 1.

Summary of the prominent modifiers

Service level is the most important of water consumption modifiers. It drives the major part of the 7 to 600 lpcd range found in exploring the literature (see table 17-A). Within the service level concept are two divisions that can be identified as modifiers in their own right: public water point vs. private residential delivery, and dry sanitation vs. flush toilet. Service level data provide household or individual level detail, very different from the ‘by country’ water consumption data that generally compresses the range of service levels into a single averaged expression. Table 17-A provides a juxtaposition of the two approaches, which seldom occurs in the literature. Water service level could also be considered a proxy for wealth, with that spectrum being a driver of water consumption, but service level appears to be the more proximate variable.

Sanitation contributes to or defines a bimodal division of ranges of consumption along the binary question of dry sanitation vs flush toilet. The maximum is generally 50 lpcd for persons using the former, with a minimum 100 lpcd for the latter. The sanitation type interacts with service level, conservation policies, and water-saving fixtures. For emerging economies, country averages (of water consumption data) obscure the dichotomy (see the notes to table 17-B).

Metering has documented capacity to reduce consumption, quantifiable at 10% to 15% for large metropolises, and up to 50% in rural community settings. Metering is a politically charged modifier, with metering proponents sometimes claiming higher urban numbers (e.g. 20%) and metering opponents unwilling to concede that any water saving advantage exists, especially after metering costs (meters, installation, reading, billing) are weighed in against other alternative water-saving approaches. The ability of metering to achieve water savings is tied to other modifiers: price, service level, and where the outdoor use component is large, climate.

Price is mechanically capable of modifying water consumption, but social, political, and public health considerations restrict its use as a consumption modifier at the domestic level. Indoor water demand is relatively inelastic overall but shows socially unacceptable elasticity among the poor, with the possibility to impact hygiene and health. Price can exert some socially tolerable pressure on consumption for outdoor and discretionary consumption, and outdoor consumption has been shown to be more price elastic. Ensuring universal access to water while simultaneously constraining non-essential consumptions is challenging, resulting in complex block-pricing schemes and cross-subsidies. To be effective as modifier, price must be used in conjunction with metering. The ability of price to modify consumption can also be affected by residential outdoor water use polices. Lastly, price is a revenue and sustainability tool as much or more than a consumption modification tool, further complicating its use for the purpose of consumption modification.

Climate drives outdoor water use for domestic consumption, and outdoor use can be the major portion of domestic consumption in arid climates. Its range of influence in North American settings of cool moist to hot arid is from approximately 33% to 233% of an indoor baseline of consumption (see Tables 17-E and 17-F). Climate as a consumption driver interacts with service level, applying mostly to service levels with private (to the residence) delivery.

Traditional sources can reduce new source water consumption, and as such can be considered a modifier. The impact requires case-by-case assessment however and no general numbers can be applied. Traditional source impact on new source consumption is likely to decrease over time.

Water pressure. Reducing water pressure (while staying within an acceptable range) has the potential to reduce water consumption 6-10%, assuming pressure was relatively high to begin with. Where pressure is already low, little benefit could be obtained without compromising adequate water delivery for some users and/or the quality of water delivered (depressurization causing backflow leak contamination).

Lot or family compound size is a large driver of outdoor use, which in turn is often, but not always, a large component of total use. Outdoor on-the-lot uses occur both in poor rural and wealthy urban situations. It is catalyzed by climate, see reference REUWS tables 17-E and 17-F. In the U.S. the impact of lot size is a fraction of indoor use in moist climates, but can exceed indoor use in arid climates. Likewise this modifier is of less weight for populations living largely in apartment structures. Because of the other variables, it would not be realistic to assign specific percentages or absolute numbers relating lot size to consumption levels.

Conservation technology is a component of the long-term trend toward lower domestic use in the U.S. and Europe. It is difficult to sort the technology savings from other influences, such as the higher prevalence of metering, but a reasoned estimate from looking at Rockaway et al. and comparing the REUWS 2012 update data to the original 1999 study could be in the range of 10% to 15% savings.

Number of persons per household does have a detectable impact on per capita water consumption figures, with a five-person household 25% to 40% more efficient than a two-person household. This modifier can be relevant when comparisons are made between populations with widely differing average household sizes e.g. average 2.2 in a post-industrial setting vs 5.5 in a developing world setting.

Other factors, perceived modifiers, proxies

Conservation education or behavioral measures may achieve short-term or emergency domestic water consumption savings up to 25% from baseline, but documented long-term savings are low, from 0% to 10%, and at risk for dissipation over time. Conservation is a politically sensitive modifier. Conservation efficacy may be also affected by how high consumption levels were prior to conservation efforts. As a practical matter, conservation efforts are not focused on environments where per capita consumption levels are already low. Indeed the opposite may take place to ensure adequate water for health.

Nationality is not a modifier in the literal sense, but our understanding of water consumption is to a substantial extent organized around country-by-country data and it is clear that which country you live is a determinant of how high the *average* water use is. Nationality is essentially a meta-modifier representing aggregation of differing water policies and service levels. Note that many, if not most, aspire to wealthy nation consumption patterns, though this could as easily follow a Denmark approach as a U.S. approach.

Poverty/wealth has a relationship to water consumption, but more meaning is derived from looking at the service levels that are an extension of the condition of poverty or wealth.

Differing data sources can lead to differences in stated water consumption documented in this investigation to vary widely (see Table 17-C). Possible causes/explanations are differing calculation bases (e.g. leaks included or not in the data) or differing primary sources.

A table framework for understanding

The table layouts here borrow conceptually from mosaic and composite techniques used in aerial imaging to create a large picture understood holistically through the bringing together of many smaller image fragments. Different general and technical meanings of the words mosaic and composite exist. For this investigation composite is used to refer to data from multiple sources melded together to form a larger picture, where the original data points are not discernable in the final table. Mosaic is used to refer to data from multiple sources placed together as tiles to form the larger picture, with the original data points and sources discernable in the final table. The mosaic approach is important because often the data points from any one source for water consumption are partial but of good quality; by tiling several sources together a picture able to provide more complete understanding can emerge. The tables follow the Edward Tufte principle of seeking the highest possible density achievable without compromising the efficient visual transfer of information (e.g. Tufte, 2006).

Examples of composites are *Table 5-A* and *Table 9-A*. Mosaic examples include *Table 17-A* and *Table 17-B*. Where mosaic tables have a composite column, it is in italic. Many of the tables provide space (sources A, B, C) for comparing up to three sources for a given item, but not all items have three different sources. Blanks in these tables do not indicate holes in the data, but rather simply less than three sources for that particular item.

Table 17-A allows us to glimpse a wide range of domestic water consumption values in one display. A comprehensive service level scale anchors the table in the middle, with ‘edge-of-survival’ realities and international minimum standards at top, and a selection of national average values at the bottom -- reflecting consumption of the world’s most populous countries, the highest consumption countries, and the lowest consumption countries.

Table 17-A. Three contours of estimated/recommended domestic consumption

Domestic water consumption concept (lpcd)	Source A	Source B	Source C	Best estimate	Notes
Int'l standards and guidelines --------	--------	--------	--------	--------	--------
Absolute min. to sustain life – domestic very short term only	2 EPA	3 Howard et al.	5 Howard et al.	***5***	C → hard phys. labor, pregnancy
Minimum standard – refugee or disaster setting	7 WEDC	15 SPHERE	20 WHO	***15***	Emergency only low as 7; WEDC
Rainwater from roof catchment	15 USAID			***15***	Varies w/ rainfall, dry season, roof m2
Minimum for acceptable living	20 WHO	50 Gleick	135 Chenoweth	***20*** ***120***	= w/dry sanitation = w/flush toilet
Service scale --------	--------	--------	--------	--------	--------
Well source, >1 km distant	5 Howard et al.	7 Hofkes	10 WEDC	***7***	4 gal bucket 33 lbs (15l, 15k)
Well source 500 to 1000 m	12 Hofkes	16 WEDC	20 Howard et al.	***14***	1000 m 'improved' threshold
Well source 250 to 500 m	20 Hofkes	16 WEDC	20 Howard et al.	***18***	
Well source 100 to 250 m	20-30 Hofkes	17 WEDC	20 Howard et al.	***20***	
Well and handpump, <100 meters	30 Hofkes	20-40 WEDC	20+ Howard et al.	***25***	
Standpost, <100 meters	30 Hofkes	20-40 WEDC	20+ Howard et al.	***30***	Same dist., but less work to retrieve
'In the yard' single tap	40 Hofkes	50 WELL	50 Howard et al.	***45***	Lowest private residential level
Single in-house tap	50 Hofkes		50 Howard et al.	***50***	Generally a kitchen tap
Single tap w/ limited productive uses	70 Morairty			***70***	e.g. livestock, kitchen garden
Multiple in-house connection Inc. Flush toilet + shower/bath	100+ Howard et al.	150 Hofkes	155 WELL	***150***	Int'l reference
Multiple in-house connection, inc. toilet + shower/bath + prod. uses	-250 Hofkes		-300 Howard et al.	***250***	Int'l reference
Nat./regional averages data --------	--------	--------	--------	--------	--------
Multiple in-house connection, best conservation practice, Europe	114 Vanham	107 Aquaterra	127 Aquaterra	***114***	A=pan Euro, B= Belgium, C=Neth
Multiple in-house connection Europe, standard practice	154 Aquaterra	133 Aquaterra		***143***	A=unmetered vs B=metered
Canada	375 Sharratt			***375***	
USA	575 UNDP	647 REUWS		***600***	
India	140 UNDP	139 Zetland		***140***	Rural pop. lower Urban higher
China	85 UNDP	95 Zetland		***90***	Rural pop. lower Urban higher
Nigeria	40 UNDP			***40***	
Brazil	190 UNDP			***190***	
Angola, Cambodia, Ethiopia, Haiti, Rwanda, Uganda	<25 UNDP			***20***	

Table 17-B displays side-by-side ingestion, domestic, and footprint values for a representative selection of countries around the world. Population data is also provided, along with country consumption aggregate totals for domestic and footprint water in the right side columns. China, India, and the U.S. occupy the top three spots in both domestic and footprint water consumption (note numbers in bold).

Table 17-B. Water consumption -- ingestion, domestic, and footprint

Consumption Definition → **Country**	**Ingestion** Howard & Bartram lpcd	**Domestic** UNDP lpcd	**Footprint** Hokestra & Mekonnen Lpcd	**Dom as a % of FP**	**Pop Mil.** 1,000 ,000	**Total country domestic water consumption domestic x pop** Thous M3 p/d	**Total country footprint water consumption FP x pop** Thous M3 p/d
Mozambique	**3**	**7**	**3010**	**0.2**	23	161	69230
Uganda	**3**	**20**	**2970**	**0.7**	35	700	103950
Haiti	**3**	**20**	**2790**	**0.7**	10	200	27900
Ethiopia	**3**	**20**	**3150**	**0.6**	86	1720	270900
Cambodia	**3**	**20**	**2960**	**0.7**	15	300	44400
Nigeria	**3**	**40**	**3400**	**1.2**	174	6960	591600
Bangladesh	**3**	**50**	**2190**	**2.3**	153	7650	335070
China	**3**	**85**	**2950**	**2.9**	1362	***115770***	***4017900***
India	**3**	**140**	**2980**	**4.7**	1238	***173320***	***3689240***
UK	**3**	**150**	**3480**	**4.3**	64	9600	222720
Brazil	**3**	**190**	**5510**	**3.4**	201	38190	1107510
Germany	**3**	**200**	**3840**	**5.2**	81	16200	311040
France	**3**	**280**	**4930**	**5.7**	66	18480	325380
Spain	**3**	**320**	**6710**	**4.8**	47	15040	315370
Mexico	**3**	**365**	**5340**	**6.8**	118	43070	630120
Japan	**3**	**375**	**3700**	**10.1**	127	47625	469900
Canada	**3**	**375*** *Sharratt	**6500**	**5.8**	35	13125	227500
Australia	**3**	**490**	**6440**	**7.6**	23	11270	148120
USA	**3**	**575**	**7800**	**7.4**	317	***182275***	***2472600***

Notes regarding 17-B:

-Domestic and ingestion water is included in the footprint values.

-For transitional/emerging countries, a domestic consumption number between 50 and 150 likely does not indicate that many people actually use that amount. More plausible is that there are a large number of those who have consumption below 50 lpcd (w/dry sanitation) offset by an also substantial number who have consumption above 150 (w/flush toilets) -- a barbell demographic. In contrast, fully developed, predominately urban countries have vanishingly small populations using dry sanitation, which allows a more accurate overall understanding to be derived from the average. Poorest nations likewise have large populations using predominately dry sanitation or practicing open defecation, resulting in a more reliable indication of central tendency from the given average. For the highly relevant cases of the two most populous countries of the world, China and India, India's average of 140 lpcd may be fundamentally different from the U.K.'s seemingly similar 150 lpcd. In the U.K., the 150 lpcd derives from a near universal diffusion of modern water infrastructure with middling efficiency (Aquaterra, 2008), where India has a vast segment of the population using dry sanitation or no sanitation (open defecation) along with a large urban population possibly using more water (old inefficient fixtures, leaks) than is the norm in the U.K. The case of China may be similar with possibly less leaks in urban systems or different urban/rural proportions explaining the somewhat lower numbers.

Table 17-C provides a comparison of domestic consumption numbers from two differing sources for a representative selection of countries, to give a feel for the spread

of the data. For the eleven countries where there are two values for a country, more than half of the time there was good agreement between the sources (11% or less discrepancy). Between these two sources, no discrepancy greater than 50% was found and just two cases where the discrepancy was noteworthy: for Mexico and Denmark, 45% and 46% respectively. However Euro-specific sources (e.g. Aquaterra, Vanham) showed rather different ranges of consumption numbers with discrepancies for the exceeding 50% for the countries that can be compared (listed by both sources).

Table 17-C. Domestic water consumption – two sources

Water consumption source → (lpcd) Country	Global Water Intel Zetland, D. 2013	UNDP Human Dev Report 2006	Disc rep ancy %	Mean value
Mozambique		7		7
Haiti		20		20
Ethiopia		20		20
Cambodia		20		20
Nigeria		40		40
Bangladesh		50		50
China	95	85	11%	90
India	139	140	<10%	139
UK	139	150	<10%	144
Brazil		190		190
Germany	151	200	24%	175
Denmark	114	210	46%	162
Turkey	238			238
France	232	280	17%	256
Spain	342	320	<10%	331
Mexico	200	365	45%	282
Russia	368			368
Japan	373	375	<10%	374
Australia	605	490	19%	547
South Korea	552			552
USA	616	575	<10%	595

Table 17-D provided a summary of data for a collection of relevant aspects of water consumption that don't necessarily fit into another table or other display.

Table 17-D. Other consumption-relevant factors

Factor	Source A	Source B	Source C	Combined estimate	Notes
Affordability thresholds ***Max acceptable percent of hh income***	2.5% EPA	3% UN	5% McPhail		General rule <5%
Affordability cases U.S. ***Percent of hh income***	0.76% Irving TX	1.64% Oshkosh WI	4.1% Lumpkin	2%	Depends on both income and price
Affordability cases other places ***Percent of hh income***	2% Bolivia Israel, D.	7% Morrocco McPhail			
Metering affect on consumption ***Developing world context – yard tap***	50% reduc. Pacheco			25%	A= Up to %50
Metering affect on consumption ***Modern context – indoor plumbing***	31%reduc Sharratt	19% reduc Sharratt	13% reduc Staddon	15%	A = small Towns only
Leaks	>5% (Best practice)	11% Aquaterra (Europe)	50% Walker et al (Dev world)		
Differences in stated domestic water consumption levels between data sources	>100% UNDP to Vanham	<47% UNDP to Global Water Intel			Leaks, urban or rural bias
Switch to low flow fixtures in modern indoor plumbing context	10%		Up to 30%	15%	C= promotional
Consumption decline with time (per year) urban water system with modern dwellings	~0.5% Rockaway		1% AWWU	~0.75%	Supposes Conservation measures

Tables 17-E and 17-F are derived from the REUWS. The REUWS provides a solid base for well-researched water consumption figures, but suffers from two shortcomings. First, though the authors drew their data from different climatic zones, they did not attempt to provide water consumption guidance broken out on the basis of climate. Because climate has such an impact on residential consumption in the U.S., this is unfortunate and the rendering the average calculations of much less value.

The second shortcoming was simply the age of the work, but it is a shame to lose this research given its depth. With well-established trendlines for change of water consumption it was possible to correct this data for current use through careful extrapolation. Rockaway et al., AWWU, and the REUWS's own limited scope update preview data (2012) all graph or reported a 15% to 20% decline in North American residential consumption over approximately the past 20 years. No sources were found contradicting these trends. Applying the most conservative (least change) interpretation of this broad trend-line (0.75% per year x 15 years = 11% decline) to the original REUWS data (1999), we could extrapolate an educated estimate of present numbers. Further, the REUWS gives the raw data but does not fully exploit in the analysis the impact of regional climate on water consumption. Given that indoor consumption is relatively stable and outdoor consumption varies between ~33% and ~233% of the indoor amount, there is an opportunity to provide much more specific, regionally appropriate data based on a simple breakdown between cool and moist climates to hot and arid. Tables 17-E and 17-F display these calculations.

Table 17-E. 2x2 to improve accuracy of domestic water consumption estimates

Amount over indoor use US =235 lpcd	Moist	Arid
Cool	33%	150%
Hot	54%	233%

Even if substantial imperfections exist in the original data or the new calculations, attention to this one determinant leads to much improved regionally appropriate climate-specific numbers – note the difference between the Seattle and Scottsdale values. This determinant could be reduced to a single decision tree question: Which of the following template cities corresponds most closely to the climate of the city in question? 1. Seattle WA, 2. Tampa FL, 3. Boulder CO, or 4. Scottsdale AZ. A general countrywide adjusted average is also included in the table.

Table 17-F. Extrapolation of REUWS to 2013 with local climate breakdown

Domestic/household Consumption situation lpcd	Indoor	*OD/ID %*	*OD/Tot %*	Outdoor	Total	*ET*
REUWS 12 city mean 1999	**265**	*138*	*58*	**386**	**651**	*41*
REUWS mean estimate 2013 (11% decline based on update)	**235**	*138*	*58*	**324**	**559**	*41*
REUWS derived estimate 2013 Cool, moist; e.g. Seattle	**235**	*33*	*25*	**78**	**313**	*30*
REUWS derived estimate 2013 Hot, moist; e.g. Tampa	**235**	*54*	*35*	**127**	**362**	*38*
REUWS derived estimate 2013 Cool, arid; e.g. Boulder	**235**	*150*	*60*	**353**	**588**	*44*
REUWS derived estimate 2013 Hot, arid; e.g. Scottsdale	**235**	*233*	*70*	**548**	**783**	*58*

While the data broken down this way unquestionably loses some statistical power from the smaller dataset for each city (avg. n=99) as opposed to when taken all together (n=1188), any resulting increase in range of error is a trifle compared to knowing whether the outdoor water use is approximately 33% of the indoor water use or 233% (25% and 70% respectively if referencing total water use). A check with a Phoenix/Scottsdale civil engineer revealed the use of exactly the ‘70% of total use’ figure as a traditional and current standard estimation of outdoor water use in those arid cities (personal communication, Patricia Butler, 26 December 2013). At the other end of the data spread, for a cool moist climate, the Newport OR data (see Figure 15-2) corroborated the 25% figure for outdoor use. Note: Minor possible discrepancies in original REUWS reported data were not corrected here, and have no effect on the general contours of the presented information. In particular, the REUWS report stated that over the 12 cities, 58% of total water consumed goes to outdoor purposes. This datum is widely repeated in the literature, including within EPA and USGS documentation. The numerical data in the REUWS point to a slightly higher percentage (59 or 60%), which may be attributable to internal corrections carried out on their raw data, handling of unknown values, or actual errors (least likely).

Table 17-G combines various sources and provides detail on ingestion water.

Table 17-G. Range of ingestion water needs

Ingestion table Consumption (lpcd)	**Source 1**	**Source 2**	**Source 3**	**Best estimate**	**Notes**
Minimum standard, no gender identified	2.0 EPA	2.5 WHO	2.75 Sphere	**2.5**	If fraction round to 3
Male	3.7 (3.0) IOM	2.9 Howard Bartram		**3.0**	
Female	2.7 (2.2) IOM	2.2 Howard Bartram		**2.2**	
Children	1.7 (1.4) (age 4-8) IOM	1.0 Howard Bartram	1.0 EPA	**1.2**	
During pregnancy	3.0 (2.4) IOM	4.8 Howard Bartram		**4.5**	
Lactating	3.8 (3.0) IOM	5.5 Howard Bartram		**5.0**	
Manual labor In high temperature Intensive sport activity		4.5 Howard Bartram		**4.5**	Hearsay up to 7 for athletes

IOM numbers include the water intake found in food, which the Mayo Clinic (2013) posted as approximately 20% of our total water intake. The Howard and Bartram numbers presumably do not include water in food. Adjustment for the food-water portion was made to the IOM numbers and provided in parentheses.

Table 17-H provides a 18 case domestic water consumption comparison on one page that allows the user to choose a closely matching case to their inquiry or requirements. It also illustrates in another form answers to the question "How much water do we consume?" under differing circumstances.

Table 17-H. Domestic water consumption grid (lpcd in bold italic at bottom)

Developing world Dry sanitation 1000 meters from source Hand carry (Hofkes) ***7***	Developing world Dry sanitation 100 meters from source (one block) Hand carry (Hofkes; Howard) ***20***	Modern world camping trip Open defecation Bring water or gather from streams Hand carry (Author calculations) ***7***
Developing world Dry sanitation Yard tap Hand carry (Hofkes; Howard ***45***	Developing world Dry sanitation In house tap Not including productive uses (Hofkes; Howard) ***50***	Developing world Flush toilet Full amenities Not including productive uses (Hofkes; Howard) ***150***
Developing world Urban environment Flush toilet, leaky water system No effective metering (Walker) ***Up to 500***	Northern Europe Urban environment Best existing technology Metering, conservation commitment (Aquaterra) ***~110***	Europe Urban environment Older technology, No metering (Aquaterra) ***~155***
Future scenario Europe Urban environment Cutting edge tech Modest in-residence recycling (Author etimate) ***~95***	Future scenario Europe Urban environment Cutting edge tech Agressive in-residence recycling (Author estimate) ***~80***	Future scenario Europe Urban environment Cutting edge tech Utiltiy full water recycling (Author estimate) ***~40***
USA Urban environment Older technology Cool moist climate, outdoor watering (REUWS plus author calc) ***~300***	USA Urban environment Older technology Hot arid climate, outdoor watering (REUWS plus author calc) ***~800***	Future scenario USA Urban environment Cutting edge tech Metering, conservation commitment (Author estimate) ***~225***
Denmark - source 1 (ex. discrepancy) Urban environment Best existing technology Metering, conservation commitment Just residence? (Aquaterra, 2008) ***~122***	Denmark - source 2 (compare to 1) Urban environment Best existing technology Metering, conservation commitment Gross average? (UNDP, 2006) ***~210***	Alaska northern village Permafrost environment Special water adaptations for cold Full amenities including toilet Strong conservation incentive ***~78***

Are the modifiers additive?

The literature provided little illumination on this, and oblique references in situations where multiple water savings techniques are employed do not appear to support the idea that water savings from each of several modifiers can be strictly added up. For example, low flow fixtures and meters each separately introduced may achieve a 15% water savings but no evidence was found to support the idea that the introduction of both would achieve 30% savings. At the same time, water delivering entities frequently employ multiple water savings approaches, indicating that at least some marginal benefit is perceived from the additional effort. Such multi-prong approaches may also reflect a mentality of 'measure x might succeed among those where measure y fails', providing redundancy rather than necessarily cost-justifiable actual benefit.

While a neat mathematically framework from which precise water consumption could be determined by connecting the multiple impacts of the modifiers does not appear realistic, having enough comparative examples can frame the range of expected values for a given situation fairly well. This is the objective of the tables.

The starting consumption level may be relevant for determining the potential capacity for modifiers to provide water savings. At face value, water savings potential is greater if the water consumption baseline level is higher. For example if a UNDP average of 260 lpcd drawn from six wealthy water-conscious European countries (see Fig. 5-7) can be taken as a best-practice benchmark for industrialized nations, then an expectation of achievable potential savings for Japan, with a current consumption of 375 lcpd, might be proposed to be 115 lpcd (375 minus 260). The frame of potential savings for the United States with a current consumption of 575 lpcd, however (by the same UNDP source), would be nearly three times as much, at 315 lpcd. During this investigation, no information specifically illuminating this issue was encountered.

Using the data of the tables and summaries

Applying the data of water consumption is not so much a matter of locking onto an exact number, but rather of finding a credible anchoring to the circumstances of interest or triangulating several data points that bear some resemblance to the desired circumstances (even if not a perfect match). Following are potential use scenarios.

Estimating U.S. based domestic water consumption: Determine region of interest according to climate (cool/hot; moist/arid), then use Table 17-F. REUWS extrapolated data assumes metering, progressive pricing, and some level of modern water conserving fixtures. Triangulation may be useful with ‘full amenity’ and the ‘country average’ values on Table 17-A. Framing with the ‘moist to arid’ range of the REUWS values of 17-F may provide more meaning to the other values, which are presumed to be averages across a range of climates.

Developing world rural water system: Determine desired service level on Table 17-A, which provides multiple sources for each service level. Possibly adjust somewhat for metering, Table 17-D.

Sanitation choice decision-making: Review narrative results summary for sanitation; compare use levels for dry vs. flush in Table 17-A, which can then be evaluated with respect to water availability (and water unit cost). See sanitation chapter for additional perspective and weighing factors that better take into account public health issues and contamination externalities.

Engaging coherent generalist dialogue on domestic water: A range of framing references are in Table 17-A, from human need, service-level, and national averages perspectives (including low-income and high-income countries). Table 17-H complements 17-A with a collection of domestic water consumption scenarios.

Engaging dialogue across water footprint and domestic categories: Table 17-B provides differentiation between footprint and domestic water for both low-income and high-income countries.

Weighing whether to add metering to existing water system: Determine if system is urban, small urban, or rural. Find functional service level on Table 17-A and adjust in accord with Table 17-D.

Evaluating how closely to trust water consumption information: Use Table 17-C to frame the notion of range of differences (due to definition issues more likely than errors of measurement).

Price setting for water in poor rural setting: Review narrative results summary for price; review Table 17-D for reference examples of % of income devoted to water in low-income and high-income country scenarios.

Evaluating possible water conservation options: Review narrative results summary section, then individual modifier chapters for more information on chosen options. Compare scenarios of Table 17-H for framing water goals.

Assessing minimum water requirement in disaster situation: Review Table 17-G for range of ingestion requirements; see top section of Table 17-A for sources on minimum established values.

Making step improvement of service level for rural water delivery: To see water consumption jump from a service improvement review Table 17-A for current and desired level of water service.

Chapter 18: Discussion

Conclusions drawn from the investigation

99% of domestic water use is defined by surroundings. There is abundant data supporting the idea that our condition of being human defines just over 1% of our direct water consumption; our surroundings the other 99%. Regardless of how the extremes of viable or actual domestic consumption are defined (they could be stated as from ~5 to 783 lpcd or from ~7 to ~600 lpcd depending on sources), the spread constitutes an approximate 100:1 relationship.

No single unifying number for domestic water consumption, and averages taken across differing living circumstances (i.e. service levels) obscure reality rather than summarize it. The mosaic and composite tables of water consumption data presented in chapter 17, while they do not provide a single one-size-fits-all answer, do allow integration within a single eyespan the range of consumption numbers.

Domestic water as a category lives in the shadow of footprint water. This investigation project was undertaken with the notion that domestic water conservation was of critical importance. After assembling and analyzing the data, it appears that domestic water consumption issues, though clearly important and certainly tangible in our everyday lives, are not at the center of total human use of water.

A nucleus of 5 interlinked modifiers drive the bulk of water consumption behaviors: service level, sanitation choice, metering, climate (in some cases), and water saving technology.

Water scarcity. This investigation project was initiated with the view that water was in critically short supply, which justified the close attention to modifiers of domestic consumption. The notion of scarcity was not a project hypothesis but certainly an assumption. The information that emerged through the study of water footprints, realities of food production, full wastewater recycling, and desalination techology have all undermined that idea. Though more tangible, domestic water is not at the center of gravity of human water issues; footprint water is. Understanding modifiers is useful not primarily because water is short but because using all resources wisely makes sense.

Though water is not scarce in a physical sense, as a valuable good it is very much so in an economic sense, leading to the issue of disparity: water will remain scarce for some people not because of the lack of water but because of a lack of money. Barton Thompson, co-director of Stanford University's Woods Institute for the Environment, commented in a recent article in the San Jose Mercury News on the current California drought (Rogers, Jan. 25, 2014) that we don't really run out of water, we only run out of cheap water. The Millennium Development Goal 1 puts food and poverty together as one goal because securing adequate food is more than anything else a matter of money and resources. The same is true of domestic water.

Constraints to the use of price, for valid social and public health motives, to regulate supply and demand can exacerbate the perception of physical scarcity as a result of market failure. The targeting and application of subsidies or cross-subsidies for water is fraught with challenges. This area alone would provide adequate material for a substantial thesis. (Note: In the rural Alaska context, for confronting the money dimension of water there is a need to engage users and other stakeholders in better dialogue about costs, expensive technology, and sustainability. The range of options are not necessarily fully in the comfort zone of health professionals and engineers, who may do well to step back from their assumptions and ownership of the thinking regarding domestic water and give beneficiaries clear comparisons, allowing autonomous decision making. Some cite federal restrictions on lower level choices as hamstringing options.

Water, food, and energy are bound in a tight nexus, and behave as commodities in some similar ways. Analogies to ‘peak oil’ are not out of place, with vast quantities of both supply side water and demand side water savings available to us, though like oil, at increasing difficulty of access and cost (drilling deeper, reverse osmosis wastewater recycling, appropriating footprint water). Also in a parallel with oil, the rising cost of obtaining additional water resource virtually guarantees modulation of demand. We are not running out of oil, food, or water -- from a nexus approach each holds potential to ease demand upon or increase availability of one or both of the others.

A pronounced alarm bias thrives in both popular and academic literature about water. To state “there is no crisis” is equivalent to confirming the null hypothesis: the disadvantage that ‘less exciting’ null hypothesis conclusions suffer in journal publication and popular press is well documented.

Meat as water supply buffer or water mining resource. Adequate accounting for environmental externalities of meat production could potentially alone solve a generation worth of water stress. There is already much research and lines of connection do exist, but the messages are framed in an entirely non-productive way: “to eat a hamburger is equivalent to the consumption of 3000 liters of water, (i.e. you bad person)" vs. "let's create a hamburger with a tasty meat+grain formation which could save 1500 liters of water, reduce calories, provide more balance nutrition, and improve health". The aura of 100% meat as synonymous with 'pure' and the persistent notion that combinations of less than 100% meat is ersatz or adulterated (rather than a good product in its own right) constitute major impediments. Hybrid formulations of meat plus quick oats, grated carrots, and spices can taste superior to pure beef (i.e. high quality meat loaf), but are stigmatized. A so called 'water crisis' may be a health improvement tool/driver/benefit if the concept of less meat in the diet assumes a greater prominence as a result of it.

Fully recycled wastewater, at about half the cost of desalination, provides a future path for water sufficiency in a modern context at a steep but not insurmountable cost. In spite of the negative public perceptions of recycled water for domestic use, both civil engineers working in the water field interviewed for this project mentioned the large-scale introduction of recycled wastewater directly into potable water supplies as inevitable in the U.S. within the next decade, with planned infrastructure to that end already under construction.

Limitations of this investigation project

In the end the breadth and depth of the literature on the topic leads beyond the scope of a single thesis or investigation project; as such, this work is suitable to illuminate ideas on the modifiers of water consumption but cannot be considered truly exhaustive on any of the modifiers. This may or may not be a serious flaw. Non-exhaustive study still allows reference-framing numbers to be established, but more caution is required in interpretation and acceptance. The data resolution needed for understanding in this case is not particularly high: exact numbers are less important than providing more clarity about to what the numbers refer and the underlying assumptions from which the numbers are drawn. Differing results from similar keyword searches in Ebsco database, Google, Google Scholar, JSTOR, etc., reinforced the impression that the literature search has not been exhausted, though many times the same underlying data circulated from one place to another, giving some indication of adequate saturation.

Exploration of the modifiers of domestic water consumption can occur on at least four separate axes:

1) high-income nation ----- low-income nation;

2) urban setting ----- rural setting;

3) wealthy individual water consumer ----- poor individual water consumer (within a single country or region); and

4). extremely high-consumption wealthy nations (i.e. United States) ------ extremely water efficient wealthy nations (e.g. Denmark, Estonia)

In this project, it was not possible due to limitations of time and size of final result to adequately cover all axes in each topic; it in places more of a patchwork delving or sampling, with the data cited at times US-centric, other times Africentric depending on what seemed most relevant to the immediate area of inquiry.

Discrepancies regarding water consumption data are everywhere, in part because the differing definitions of consumption. Anyone with strong interest in challenging the figures here could find contradicting data somewhere. The proportion of secondary data to primary data appears high, with many citations leading back to a relatively small number of empirical studies.

Issues of water quantity are inevitably tied to water quality in one way or another. Water quality is not normally an intentional modifier of domestic water consumption in circumstances created by design but could exercise a braking effect on water use in some highly compromised situations. And while water quality is not a modifier of water demand it is a factor in selecting sources that can provide water for consumption, *so could be considered a modifier of water supply*. Advances in wastewater recycling and desalination technology are lowering the barriers to the use of low quality water (whether from footprint or domestic reuse sources), but even the best results in this area will yield water at costs higher than the public has experienced in the past. The scope of this investigation did not include inquiry on the water quality to quantity interface.

The framework for evaluation of the literature was developed on the march, evolving to meet the demands of the undertaking. While this investigation broadly followed relevant criteria for evaluation of literature, it lacked a systematic framework for close comparative evaluation. For the nature of the investigation, this did not appear to compromise the selection of references, but a framework might have streamlined the work. Though not part of the APA standards, references could have also been improved by inclusion of the database/engine in which they were found (e.g. PubMed, JSTOR, Google Scholar, Yahoo) along with the exact query that generated the selection.

Though the interviews had a structured template, the actual conversations immediately took on an open ended flavor and it was not feasible to follow the script. Though the data was less systematic, they provided good input to the specific areas covered.

Future directions

There is an urgent need to address the “non-addressing” of dry vs flush sanitation within the Millennium Development Goal 7-c (they both may qualify as ‘improved’ sanitation, but there are fundamental differences between them that call for clear delineation). Within that there is a specific need to identify the externalities better and pin them on the respective technologies, especially as regards the installation of flush toilet solutions without proper sewage systems and sewage treatment in place.

Disparity deserves to supplant scarcity as the operative word around situations of not having enough water. The crisis mentality of scarcity is counterproductive as well as inaccurate, and crisis fatigue is paralyzing. A positive “we can solve this” message would potentially be both more functionally useful and more literally accurate.

There is a need for reifying the links between food, diet, obesity, and water. The health benefits of lower water intensity food constitute a magnificent win-win for public health. This investigation is a small contribution in this direction, but the concept is grossly underexplored.

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(Links terminating in .pdf may need to be pasted directly into a browser to load correctly)

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Appendices

Appendix A: Key Informant Interview request script

My name is Eric Lespin; I am a student in the Master's of Public Health program at the University of Alaska Anchorage. My thesis in this program is on the topics of water consumption, human infrastructure, and health. I would like to ask you if you have time for a brief interview as a professional courtesy, because of your expertise/knowledge (specify in more detail if appropriate) related to my area of study. The interview shouldn't run more than 20-30 minutes. If you are available for an interview, I can meet at a location and time convenient for you. If your schedule is heavily booked or if for any other reason an interview would be an inconvenience, please don't hesitate to let me know.

In my thesis, I may quote you, cite references that you mention, or attribute to you views that you share. If for whatever reason you prefer to remain anonymous however, I will respect that wish if expressed to me (at any point, including after the interview). Additionally, if there is any information that you share with me that you would prefer that I not use in my work, for whatever reason, I will also respect this.

My contact information is ericlespin@gmail.com and 907-351-3121. Elizabeth Hodges Snyder at UAA in the Department of Health Sciences is my thesis chair, available at afeh1@uaa.alaska.edu and 907-786-6540. Lastly, as a research activity subject to oversight by an institutional review board, I'd like to clarify that this interview is requested as courtesy to the researcher; it does not carry any anticipated risks, and does not provide for any direct benefits to the interviewee other than possible mention in the context of the thesis work.

Appendix B: Interview question guide

Appropriate for all

1. I'm seeking to learn more about how much water we need and use under circumstances that may be influenced by multiple factors, including the building infrastructure for human habitat. Please describe where your work may intersect with providing water for human consumption. How do you see what you do as influencing water consumption, if it is that you feel it does

Health or sanitation professionals

1. What are the sources you use for determining the amount of water needed in the circumstances you deal with? (e.g. personal experience, local norms, national standards, technical design parameters, academic texts, peer review journal findings, professional guides)
2. Do you feel the data you rely on are essentially accurate?, not very inaccurate?, exact?, inexact?, complete?, incomplete? Why?
3. Here are a number of factors that may influence human water consumption (share appropriate factors based on interviewee's area of experience). Which do you consider most relevant? Least relevant? How do you see their interrelation? What information do you feel is missing from the picture?
4. For you to make use of water consumption data reflecting various modifying factors, how would you like to see the information presented? Any thoughts as to formats for integrating the modifying factors?
5. After a certain point, more water will not make people any healthier. Below a certain point, reducing water availability will unquestionably have an impact on health. Where would you personally assign numbers to those points?
6. What is your sense of the best path for getting the highest health and quality of life benefit for the least amount of water and cost of delivery system? (as regards technologies, system type, service level, infrastructure context, human behavior, finances, policy)
7. What is your sense of the biggest impediments to adequate access to water for the populations with which you work?
8. Water is a multidisciplinary matter, affecting or being affected by other disciplines. Looking within your field and across disciplinary lines, where do you see areas of misinformation or misunderstanding? Who do you collaborate with?
9. What issues related to human water consumption and meeting that need do you feel are not on the collective radar screen today, but will become important in the near or medium-term future?

Building infrastructure professionals (architects, designers, project managers)

1. If you rely on water related information sources in your work, what are they? (e.g. personal experience, local norms, national standards, technical design parameters, academic texts, peer review journal findings, professional guides)
2. Do you feel the data you rely on is essentially accurate?, not very inaccurate?, exact?, inexact?, complete?, incomplete?
3. Here are a number of specific factors that from what I understand may influence human water consumption . . . (share appropriate factors based on interviewee's area of experience). Does your work give you a sense of which are most relevant? Least relevant? How do you see their interrelation?
4. Is there important information you feel is missing from the picture?
5. For the circumstances regarding infrastructure that you work with, what are your estimates of per capita water consumption (or do you deal with the water issues)?
6. What infrastructure changes in your mind would increase or decrease the individual water use?
7. As a professional but non-expert in water matters, how would like to see the information about water use presented?
8. What is your sense of the biggest impediments to adequate access to water for the populations with which you work?
9. Your profession is indirectly involved with some aspect of water for human use. Water is a multidisciplinary matter, affecting or being affected by other disciplines in varying degrees. Looking within your field and across disciplinary lines, where do you see areas of misinformation or misunderstanding?

Funders and proposal writers for projects with infrastructure component

1. For the circumstances regarding infrastructure that you advocate or fund, what are your estimates of per capita water consumption (or do you deal with water consumption issues)? What sources or experiences do you rely on to arrive at those conclusions, if applicable? What infrastructure changes in your mind would increase or decrease the individual water use?
2. As a professional involved in a funding component of infrastructure, do you feel in a position to make well informed decisions regarding the water consumption impact of those decisions?
3. Here are a number of specific factors that from what I understand may influence human water consumption . . . (share appropriate factors based on interviewee's area of experience). Does your work give you a sense of which are most relevant? Least relevant? How do you see their interrelation?
4. Is there important information you feel is missing from the picture?
5. As a professional but non-expert in water matters, how would like to see the information about water use presented?

Appendix C: Meat calorie calculations

Meat consumption caloric proportion of U.S. diet

	Meat Contrib. (1)		Total diet (2)		Meat c/p/f
Carbohydrates			.48		
Protein	.40	x	.16	=	.06
Fat	.20	x	.34	=	.07
Meat portion of diet	.15				~ .13

1. Daniel et al. (2011)
2. Austin et al. (2011)

Appendix D: Grain to beef calculations

There is a wide range of claims regarding edible grain to edible meat conversion ratios. This section attempts to create the reasoning and calculations behind the differing claims, showing how each could have been derived.

Basic calculation data:

Kcals in 1 lb of corn, dry yellow = 1655
Kcals in 1 lb of ground beef (80% lean, 20% fat) = 1152
Kcals in 1 lb of ground beef (70% lean, 30% fat) = 1506
Cattle at feedlot need ~5.6 lbs grain feed for each 1lb weight gain
Cattle finish at ~1250 lbs
General rule that 2800 lbs corn required to finish animal
Edible meat yield ~48% of total animal weight
1250 lbs x .48 =~600 lbs yield

Ratio 1, corn calories to meat (80% lean)

2800 lbs corn x 1655 kcal =4,634,000 kcal
600 lbs meat x 1152 kcal = 691,200 kcal
4,634 / 691 = **6.71 grain to meat** (80% lean) calorie ratio
Reasoning: 4.6 million kcal in, 0.7 million kcal out.
Ignores pasture and feed inputs prior to feedlot.
Pasture could support other crops.

Ratio 2, using 70% lean 30% fat meat as reference point:

2800 lbs corn x 1655 kcal =4,634,000 kcal
600 lbs meat x 1506 kcal = 903,000 kcal
4,634 / 903 = **5.13 grain to 70% lean meat** calorie ratio
Mean value between first two calculated ratios 5.13 and 6.71 = 5.92
Reasoning: same as 1, only using fattier meat as reference.

Ratio 3, calculation removing the non corn weight gain component

Consider that cattle put on more than half their total weight from forage:
Cattle enter feedlot at ~750 lbs, only 500 lbs feed-driven weight gain
500 lbs x .48 (edible yield) = 240 lbs
2800 lbs corn x 1655 kcal =4,634,000 kcal
240 lbs meat x 1506 kcal = 361,440 kcal
4,634 / 361 = 12.84 grain to meat calorie ratio
If food waste (U.S. levels ~29%) were applied to this ratio:
12.84/.71 = **18.08**; approaches the 20:1 ratio occasionally claimed
Reasoning: Only feedlot weight gain should be counted.

Ratio 4, using 5.6 pounds corn to one pound meat finishing figure:

One pound corn = 1655 kcal
One pound meat (70% lean) = 1506 kcal
Corn to meat calorie conversion 1655/1506 = 1.10
(5.6 x 1.10) = **6.16 grain to meat** calorie ratio
Reasoning: Energy of grain to energy of meat.
Ignores carcass waste of 52% (used for other products).

Confounds

--Almost all the animal is used, for some purpose, not just the meat portion
--Forage land could also produce grain for human consumption, provide wildlife habitat, or watershed land
--Some ratios compare pounds and others caloric energy

Ratio 5, at the other end of the spectrum from ratio 4:

2800 lbs corn per 1250 lb animal
2800 / 1250 = **2.24 lb corn per 1 lb of animal** (not meat yield)
Reasoning: End result of 2800 lbs of corn is 1250 lbs of animal.
This ratio is lbs to lbs rather than kcal to kcal
This ratio ignores significant forage inputs and meat waste

1. Cooperative Extension Service. (2008): Cattle/beef information
2. Convert-to. (undated): Corn pounds and kcals
3. Fat secret. (2013): Calories for different fat content beef

Appendix E: Extra weight carrying burden

For the U.S.:

1. how much excess weight is being carried, 2 methods
2. what does this mean in terms of calorie consumption;
3. how does this translate to in terms of water consumption.

How much extra weight method 1
From CDC stats

www.cdc.gov/nchs/fastats/overwt.htm

Centers for Disease Control and Prevention
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Obesity and Overweight

(Data are for the U.S.)

- Percent of adults age 20 years and over who are obese: 35.9% (2009-2010)
- Percent of adults age 20 years and over who are overweight (and not obese): 33.3% (2009-2010)

Source: Health, United States, 2011, table 69 [PDF - 9.8 MB]

- Percent of adolescents age 12-19 years who are obese: 18.4% (2009-2010)
- Percent of children age 6-11 years who are obese: 18.0% (2009-2010)
- Percent of children age 2-5 years who are obese: 12.1% (2009-2010)

Source: Prevalence of Obesity in the United States, 2009-2010

Average male height: ~69”; average male weight ~195lbs
Average female height: ~64”; average female weight ~166lbs

Standard Body Mass Index table

BMI	Height (in)																		
	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76
Wgt. (lbs)	4'10"	4'11"	5'0"	5'1"	5'2"	5'3"	5'4"	5'5"	5'6"	5'7"	5'8"	5'9"	5'10"	5'11"	6'0"	6'1'	6'2"	6'3'	6'4'
100	21	20	20	19	18	18	17	17	16	16	15	15	14	14	14	13	13	13	12
105	22	21	21	20	19	19	18	18	17	16	16	16	15	15	14	14	14	13	13
110	23	22	22	21	20	20	19	18	18	17	17	16	16	15	15	15	14	14	13
115	24	23	23	22	21	20	20	19	19	18	18	17	17	16	16	15	15	14	14
120	25	24	23	23	22	21	21	20	19	19	18	18	17	17	16	16	15	15	15
125	26	25	24	24	23	22	22	21	20	20	19	18	18	17	17	17	16	16	15
130	27	26	25	25	24	23	22	22	21	20	20	19	19	18	18	17	17	16	16
135	28	27	26	26	25	24	23	23	22	21	21	20	19	19	18	18	17	17	16
140	29	28	27	27	26	25	24	23	23	22	21	21	20	20	19	19	18	18	17
145	30	29	28	27	27	26	25	24	23	23	22	21	21	20	20	19	19	18	18
150	31	30	29	28	27	27	26	25	24	24	23	22	22	21	20	20	19	19	18
155	32	31	30	29	28	28	27	26	25	24	24	23	22	22	21	20	20	19	19
160	34	32	31	30	29	28	28	27	26	25	24	24	23	22	22	21	21	20	20
165	35	33	32	31	30	29	28	28	27	26	25	24	24	23	22	22	21	21	20
170	36	34	33	32	31	30	29	28	27	27	26	25	24	24	23	22	22	21	21
175	37	35	34	33	32	31	30	29	28	27	27	26	25	24	24	23	23	22	21
180	38	36	35	34	33	32	31	30	29	28	27	27	26	25	24	24	23	23	22
185	39	37	36	35	34	33	32	31	30	29	28	27	27	26	25	24	24	23	23
190	40	38	37	36	35	34	33	32	31	30	29	28	27	27	26	25	24	24	23
195	41	39	38	37	36	35	34	33	32	31	30	29	28	27	27	26	25	24	24
200	42	40	39	38	37	36	34	33	32	31	30	30	29	28	27	26	26	25	24
205	43	41	40	39	38	36	35	34	33	32	31	30	29	29	28	27	26	26	25
210	44	43	41	40	38	37	36	35	34	33	32	31	30	29	29	28	27	26	26
215	45	44	42	41	39	38	37	36	35	34	33	32	31	30	29	28	28	27	26
220	46	45	43	42	40	39	38	37	36	35	34	33	32	31	30	29	28	28	27
225	47	46	44	43	41	40	39	38	36	35	34	33	32	31	31	30	29	28	27
230	48	47	45	44	42	41	40	38	37	36	35	34	33	32	31	30	30	29	28
235	49	48	46	44	43	42	40	39	38	37	36	35	34	33	32	31	30	29	29
240	50	49	47	45	44	43	41	40	39	38	37	36	35	34	33	32	31	30	29
245	51	50	48	46	45	43	42	41	40	38	37	36	35	34	33	32	32	31	30
250	52	51	49	47	46	44	43	42	40	39	38	37	36	35	34	33	32	31	30
255	53	52	50	48	47	45	44	43	41	40	39	38	37	36	35	34	33	32	31
260	54	53	51	49	48	46	45	43	42	41	40	38	37	36	35	34	33	33	32
265	56	54	52	50	49	47	46	44	43	42	40	39	38	37	36	35	34	33	32
270	57	55	53	51	49	48	46	45	44	42	41	40	39	38	37	36	35	34	33

Mid-range BMI table weight for average height (69”) male = 155 lbs. (BMI 23)
195 lbs – 155 lbs = 40 lbs. average overweight amount

Mid-range BMI table weight for average height (64”) female = 135 lbs. (BMI 23)
166 lbs – 135 lbs = 31 lbs. average overweight amount

Average excess weight per person in U.S. 71 lbs / 2 =~35.5 lbs per person (figure assumes 50/50 division male to female population, an acknowledged approximation)

Excess weight method 2
From CDC stats

www.cdc.gov/nchs/fastats/overwt.htm

CDC Centers for Disease Control and Prevention
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Source: Health, United States, 2011, table 69 [PDF - 9.8 MB]

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- Percent of children age 6-11 years who are obese: 18.0% (2009-2010)
- Percent of children age 2-5 years who are obese: 12.1% (2009-2010)

Source: Prevalence of Obesity in the United States, 2009–2010

Population obese ~36%
Population overweight ~33%
Population normal weight ~31%

Assume BMI 33 for obese (begins at 30 and is unbounded at upper side, though some tables include 'morbidly obese', a category beyond obese)
Assume BMI 28 for overweight (range 25 through 29)
Assume BMI 23 for normal weight (range 20 through 24)
For obese category average height male (69") and female (64") = 215 and 190 lbs.
For overweight category average height male (69") and female (64") = 190 and 160
For normal weight category average height male (69") and female (64") = 155 and 135
For normal (155 + 135)/2 = 145 lb population reference weight (avg btn m &f).
For obese (215 + 190)/2 = 202 lbs – 145 lbs = 57 lbs excess weight
For overweight (190 = 160)/2 = 175 lbs – 145 = 30 lbs excess weight
Multiplying the excess weight amounts by proportion in each weight category:
57 x .36 = 20.5; 30 x .33 = 10; 0 x .31 = 0;
20.5 + 10 + 0 = 30.5 lbs average overweight per person among adult population.

Appendix F: Note regarding dry sanitation in U.S. and Alaska

According to 1990 U.S. Census data, for the United States as a whole about 1.1% of households use outhouses or privies. The state with the highest absolute number of outhouses in use is California with ~68,000 outhouses, representing 0.6% of state households. The state with by far the highest percentage of households using outhouses or privies is Alaska at 12%, nearly three times the percentage of the next highest state (West Virginia), and more than ten times the national average. At the time of the 1990 census Alaska had ~28,000 outhouses or privies.

Ambivalence about the suitability of outhouses is widespread when other options are available, for example city code requiring toilets if the water lines are in place to or by any residential property, and requiring outhouses to be removed in the same circumstances.

1-Fragment from a small city code contents:

City of Westhope, North Dakota
Code of Ordinances

CHAPTER TWELVE

PUBLIC NUISANCES

ARTICLE 1 - Sanitary Nuisances

12.0101 Residence - When Sewer and Water Required
12.0102 Outhouses - Cesspools - A Nuisance

2-Fragment from a small city code narrative:

Section 278:05. Privies and Outhouses. No person shall erect, keep or maintain in the City of Owatonna, Minnesota, any privy, outhouse, earth closet, cesspool or septic tank, except those constructed in accordance with the specifications of the Minnesota State Board of Health, which may be constructed, erected, kept or maintained upon property which does not abut upon a street upon which there is a sanitary sewer line available to such property, provided, however, the City Engineer of the City may, upon application thereof, issue a special permit of a temporary duration permitting a privy or outhouse constructed and equipped in accordance with specifications of the Minnesota State Board of Health, to be used in connection with construction projects in the City and park and recreational activities of the City.

Section 278:10. Sewer and Water Connection Required. The owner of every residence or business building abutting upon any street or alley in which City water and sanitary sewer mains are maintained, shall install a toilet in the building and connect all sanitary facilities to the water and sewer mains upon notice hereinafter provided.

Section 278:20. Toilet Installation; Privy Removal; Assessment. Whenever the notice provided for in Section 278:15 is not complied with, the Council may, in its discretion, by resolution, direct the installation of a toilet and connection with the water and sanitary sewer system, or direct the tearing down and removal of such privy, outhouse, earth closet, cesspool, or septic tank, or shall direct the closing up of such private well or water supply. The cost of such installation or work shall be paid initially from the general fund and then be charged by the Council against the property benefited.

http://www.ci.owatonna.mn.us/node/4861

Appendix G: Regarding caloric burden of human water transport

From Mayo Clinic posted calorie consumption data for activities (corroborated with Harvard Health Publications calorie burn chart):

walking 3.5 mph 160 lb = 314 calories p/h
walking 2.0 mph 160 lb = 204 calories p/h
interpolation 3 mph (~5 kph) = **277 calories** p/h (5kph a commonly used assumed speed for water gathering calculations)

walking 3.5 mph 200lb = 391 calories p/h
walking 2.0 mph 200lb = 255 calories p/h
interpolation 3 mph (5 kph) = **345 calories** p/h
marginal caloric burn for extra 40 lb. at 3 mph: 345 – 277 = 68 calories p/h

Assume a 160 lb (72 kg) person, retrieving 40 lb (18 kg or 4.7 gal) water, at 3 mph (~5 kph), on 30 minute (1.5 miles or 2.4 km) round trip for water –
travel to source 0.25 hours x 277 calories p/h = 69 calories
return travel w/water 0.25 hours x 345 calories = 86 calories
total caloric burden 69 + 86 = 155 calories per trip

Questions:
1-Using cheapest food, in poorest countries, would the cost of this caloric burden exceed the 5% rule? Rice, at $0.40 per kalton (2000 kcal), could provide the needed calories for approximately $0.03 per trip, for those living on $1 per capita per day. Family could make 1.7 trips per person without exceeding 5%. Calculation does not include potential cost of water or cooking fuel, or value of food preparation.
2-The calculations based on additional body weight, which is spread around the body and possibly more efficient to carry than a container of water?

Activity (1-hour duration)	Weight of person and calories burned		
	160 pounds (73 kilograms)	200 pounds (91 kilograms)	240 pounds (109 kilograms)
Aerobics, high impact	533	664	796
Aerobics, low impact	365	455	545
Aerobics, water	402	501	600
Backpacking	511	637	763
Basketball game	584	728	872
Bicycling, < 10 mph, leisure	292	364	436
Bowling	219	273	327
Canoeing	256	319	382
Dancing, ballroom	219	273	327
Football, touch or flag	584	728	872
Golfing, carrying clubs	314	391	469
Hiking	438	546	654
Ice skating	511	637	763
Racquetball	511	637	763
Resistance (weight) training	365	455	545
Rollerblading	548	683	818
Rope jumping	861	1,074	1,286
Rowing, stationary	438	546	654
Running, 5 mph	606	755	905
Running, 8 mph	861	1,074	1,286
Skiing, cross-country	496	619	741
Skiing, downhill	314	391	469
Skiing, water	438	546	654
Softball or baseball	365	455	545
Stair treadmill	657	819	981
Swimming, laps	423	528	632
Tae kwon do	752	937	1,123
Tai chi	219	273	327
Tennis, singles	584	728	872
Volleyball	292	364	436
Walking, 2 mph	204	255	305
Walking, 3.5 mph	314	391	469

Adapted from: Ainsworth BE, et al. 2011 compendium of physical activities: A second update of codes and MET values. Medicine & Science in Sports & Exercise. 2011;43:1575.

Appendix H: Water quantity summary, T. Ritter

Table 1 - Summary of Published Recommendations for Water Quantity

Organization	Recommendation Liters / Person / Day	Storage Volume (household of 5) Liters (cubic feet)	Weight of Water (household of 5) Kilograms (Pounds) /Transported/Day
	Drinking only		
EPA	*Adult-2,Child* -1	10 (0.35)	10 (22)
Sphere	*2.5-3*	15 (0.5)	15 (33)
WHO	*3-4*	20(0.7)	20 (44)
	Cooking		
Sphere	***3-6***	30 (1)	30 (66)
WHO	***2-3***	20 (0.7)	20 (44)
	Personal hygiene		
Sphere	6	30 (1)	30 (66)
WHO	6-7	35 (1.2)	35 (77)
WHO: Laundry	4-6	30 (1)	30 (66)
	***Water waste removal** - flush systems*		
EPA: Toilet	35-71	175 – 355 (6.1 – 12.4)	175-355 (385-781)
	Total water consumption		
Sphere: disaster response minimum	15	75 (2.6)	75 (165)
CRUM: minimum piped	60	300 (10.6)	300 (660)
CRUM: standard for truck-haul system	90	450 (51)	450 (990)
WHO: very high health concern	<5	25 (0.9)	25 (55)
WHO: high health concern	20	100 (3.5)	100 (220)
WHO: low level of health concern	50	250 (9.2)	250 (550)
WHO: very low level of health concern	100 or more	500 (18.4)	500 (1100)

Ritter, T. (2011). Decentralized approaches to water and sanitation solutions: making more with less. “What are the parameters for optimal water and sanitation design to maximize health?” *Second Annual Water and Sanitation Innovations for the Arctic*. U.S. Arctic Research Commission and the Centers for Disease Control. Anchorage, Alaska. January 26, 2012.

Appendix I: Note on financing the w/s need, the world and Alaska

Extending water and sanitation services are largely dependent on external capital investment both in Alaska and the rest of the world. Global shortfall in access to water is estimated at 783 million and sanitation at 2.5 billion (WHO, 2012).

Hutton and Bartram (2008), in review of cost estimates for meeting global water/sanitation shortfall, drawing on work by the Global Water Partnership, WHO, Water Academy France, the Water Supply & Sanitation Collaborative Council, and the World Bank, frame the range between 90 and 300 billion. Their own analysis arrives at a number in the middle, at 180 billion, but to that they factor in the recurrent and replacement costs of aging infrastructure, an especially important yet often ignored cost, to arrive at $700 billion. Winpenny, in somewhat earlier but extensive analysis cites a figure of 49 billon annually to achieve full water sanitation, and sewerage coverage. Converting a perpetual 49 billion annual flow into a present value (using a 5% discount rate) would amount to a present value requirement of $980 billion.

In the Alaska scenario, approximately 6000 homes are unserved To meet this need, the cost is estimated at around $700 million (Griffith, 2012). The cost of providing water service to the 6000 currently unserved homes in Alaska would be $23,000 per capita, or on the order of $100,000 per home. The world water service estimated cost per capita is approximately $280 (based on averages derived from Hutton & Bartram).

Executive Summary

Water is a multilevel determinant of health and quality of life. According to estimates by WHO (2004, 2013), 3.6% of the DALY global burden of disease and 1.6 million annual deaths worldwide are attributable to unsafe water supply, sanitation, and hygiene.

Per capita domestic water consumption can vary up to 100-fold depending on the particular combination of living circumstances and water access (e.g. Sphere, 2011; WHO, 2003; Gleick, 1996). Framed this way, the infrastructure is a far more potent determinant of water consumption than one's condition of being human. While figures have long existed establishing how much water is required to satisfy basic needs for health under a wide range of circumstances, the information is contradictory, confusing, highly fragmented, and often separated from its context and underlying assumptions, rendering it difficult to interpret, even for those that work directly in water delivery. This deficiency in understanding can affect residential building, sanitation, and water supply projects.

Following the mode of 'desk research', this project consisted of, from the abundant literature, identifying, evaluating, quantifying, integrating, and presenting in useful form the modifiers of human water consumption. Expert interviews provided perspective on the information gathered. Credible literature sources for information on human water consumption can be broken into at least seven categories: 1) scholarly peer-reviewed articles; 2) local, state, national, and international norms or guidelines; 3) water/sanitation related textbooks; 4) professional design guides, field manuals, and

handbooks; 5) project implementation documentation from water-involved entities; 6) popular press (for public perceptions related to specific water topics); and 7) commercial informational materials.

For each modifier a base of data sources and their key points or findings were assembled. As data on the modifiers accumulated through the investigation, multiple rounds of filtering, summarization, combining, and averaging occurred to concentrate the data enough to permit integration into the results chapter, which consists primarily of a collection of tables. Where table display was not efficient or appropriate, succinct narrative ‘summaries of summaries’ were written that allow for reasonable comparison of the modifiers of water consumption in question. Where possible, quantification or approximation of differences in relative importance modifiers and management of uncertainties is done.

Lack of clarity about what even is considered ‘consumption’ complicates the discussion of human water consumption numbers under differing circumstances. There are dramatically different ways of quantifying the concept, leading to confusion resulting from apples-to-oranges comparisons in discourse and practical application, as figures unconnected to their differing underlying assumptions are tossed about. Disambiguation of the water consumption concept was necessary, which encompasses three categories of consumption: footprint, domestic, and ingestion.

(Table 5-A, different constructs of water consumption, found on pg. 51)

Consumption construct	Range of use lpcd	Approx. middle value lpcd	Relevant use	Notes
Water footprint **Also withdrawal, extraction, abstraction, consumption, water footprint, virtual water plus direct use water**	~700 to 10,000	3500	Ecologic study; understanding of impact of consumer decisions	>80% result of agricultural activity
Individual direct water use **Also consumption, residential use, direct use, potable water, domestic water, drinking water**	7 to 600	50 dev world 200 OECD nations	Human habitat design; understanding of domestic water use	Bimodal distribution Confounded by dry vs flush sanitation component and other modifiers
Water ingestion **Also consumption, drinking requirements, water intake**	2 to 7	3	Medical, nutrition, emergency and disaster situations	Confounded by water in food. Water essential to life but toxic at doses >6 liters

Given the outsized influence of the water footprint within the realm of water consumption overall, and because potential domestic water resources can at least to some degree be drawn from the footprint, issues related to footprint water abundance, scarcity, or disparity warrant an examination alongside the domestic water modifiers of consumption. In particular, some demand-side savings identifiable in the footprint (food production and consumption) hold the possibility to provide new water resources or count as security buffers against shortage.

(Table 6-A, water available for recapture from food, found on pg. 66)

Water source	**Minimum estimated available lpcd**	**High estimated available lpcd**	**Note**
Convert small portion of red meat calories to grain base (total calories constant) ***min =(100 x 6) -100 cal;*** ***max =(250 x 6) – 250***	500	1250	Based on 6 to 1 caloric advantage for grain as compared to meat created from grain
Reduce total food waste to pre-obesity epidemic levels (based on current food creation of 3800 calories per person vs 3000 in 1950s) ***Min reduction = 400 cal; max = 800***	400	800	Partial/complete return to caloric intake and food waste levels of late 1950s
***Reduce overweight to* pre-obesity levels min = 138; max = 210**	138	210	6 extra calories needed daily to sustain each pound of overweight in population
***Total lcpd recoverable* from unhealthy or waste calories**	1038	2260	

Principal modifiers of domestic consumption are service level, sanitation decision (dry vs. flush), presence of metering, use of low flow fixtures, residential lot or compound size in conjunction with climate. Sanitation decision is linked to substantial health externalities. Water line pressure, number of persons in the household, and traditional sources, may exert influence on domestic consumption, though to a lesser degree than the first six mentioned. Price appeared to have a less-than-anticipated impact, due likely to social/health restraints in applying strict economic principles, and conservation education also was found to be of limited impact. Dwelling size was found not to be a modifier. The table layouts here borrow conceptually from mosaic and composite techniques used in aerial imaging to create a large picture understood holistically through the bringing together of many smaller image fragments.

(Table 17-A, Three contours of domestic consumption, found on pg. 187)

Domestic water consumption concept (lpcd)	Source A	Source B	Source C	Best estimate	Notes
Int'l standards and guidelines --------	--------	--------	--------	--------	--------
Absolute min. to sustain life – domestic very short term only	2 EPA	3 Howard et al.	5 Howard et al.	***5***	C → hard phys. labor, pregnancy
Minimum standard – refugee or disaster setting	7 WEDC	15 SPHERE	20 WHO	***15***	Emergency only low as 7; WEDC
Minimum for acceptable living	20 WHO	50 Gleick	135 Chenoweth	***20*** ***120***	= w/dry sanitation = w/flush toilet
Service scale --------	--------	--------	--------	--------	--------
Well source, >1 km distant	5 Howard et al.	7 Hofkes	10 WEDC	***7***	4 gal bucket 33 lbs (15l, 15k)
Well source 500 to 1000 m	12 Hofkes	16 WEDC	20 Howard et al.	***14***	1000 m 'improved' threshold
Well source 250 to 500 m	20 Hofkes	16 WEDC	20 Howard et al.	***18***	
Well source 100 to 250 m	20-30 Hofkes	17 WEDC	20 Howard et al.	***20***	
Well and handpump, <100 meters	30 Hofkes	20-40 WEDC	20+ Howard et al.	***25***	
Standpost, <100 meters	30 Hofkes	20-40 WEDC	20+ Howard et al.	***30***	Same dist., but less work to retrieve
'In the yard' single tap	40 Hofkes	50 WELL	50 Howard et al.	***45***	Lowest private residential level
Single in-house tap	50 Hofkes		50 Howard et al.	***50***	Generally a kitchen tap
Single tap w/ limited productive uses	70 Morairty			***70***	e.g. livestock, kitchen garden
Multiple in-house connection Inc. Flush toilet + shower/bath	100+ Howard et al.	150 Hofkes	155 WELL	***150***	Int'l reference
Multiple in-house connection, inc. toilet + shower/bath + prod. uses	-250 Hofkes		-300 Howard et al.	***250***	Int'l reference
Nat./regional averages data --------	--------	--------	--------	--------	--------
Multiple in-house connection, best conservation practice, Europe	114 Vanham	107 Aquaterra	127 Aquaterra	***114***	A=pan Euro, B= Belgium, C=Neth
Multiple in-house connection Europe, standard practice	154 Aquaterra	133 Aquaterra		***143***	A=unmetered vs B=metered
Canada	375 Sharratt			***375***	
USA	575 UNDP	647 REUWS		***600***	
India	140 UNDP	139 Zetland		***140***	Rural pop. lower Urban higher
China	85 UNDP	95 Zetland		***90***	Rural pop. lower Urban higher
Angola, Cambodia, Ethiopia, Haiti, Rwanda, Uganda	<25 UNDP			***20***	

(Table 17-B, Water consumption: ingestion, domestic, footprint, found on pg. 189)

Consumption Definition → **Country**	**Ingestion** Howard & Bartram lpcd	**Domestic** UNDP lpcd	**Footprint** Hokestra & Mekonnen Lpcd	**Dom as a % of FP**	**Pop Mil.** 1,000 ,000	**Total country domestic water consumption domestic x pop** Thous M3 p/d	**Total country footprint water consumption FP x pop** Thous M3 p/d
Mozambique	**3**	**7**	**3010**	**0.2**	23	161	69230
Uganda	**3**	**20**	**2970**	**0.7**	35	700	103950
Haiti	**3**	**20**	**2790**	**0.7**	10	200	27900
Ethiopia	**3**	**20**	**3150**	**0.6**	86	1720	270900
Cambodia	**3**	**20**	**2960**	**0.7**	15	300	44400
Nigeria	**3**	**40**	**3400**	**1.2**	174	6960	591600
Bangladesh	**3**	**50**	**2190**	**2.3**	153	7650	335070
China	**3**	**85**	**2950**	**2.9**	1362	***115770***	***4017900***
India	**3**	**140**	**2980**	**4.7**	1238	***173320***	***3689240***
UK	**3**	**150**	**3480**	**4.3**	64	9600	222720
Brazil	**3**	**190**	**5510**	**3.4**	201	38190	1107510
Germany	**3**	**200**	**3840**	**5.2**	81	16200	311040
France	**3**	**280**	**4930**	**5.7**	66	18480	325380
Spain	**3**	**320**	**6710**	**4.8**	47	15040	315370
Mexico	**3**	**365**	**5340**	**6.8**	118	43070	630120
Japan	**3**	**375**	**3700**	**10.1**	127	47625	469900
Canada	**3**	**375*** *Sharratt	**6500**	**5.8**	35	13125	227500
Australia	**3**	**490**	**6440**	**7.6**	23	11270	148120
USA	**3**	**575**	**7800**	**7.4**	317	***182275***	***2472600***

(Table 17-H, Water consumption grid, in lpcd, found on pg. 198)

Developing world Dry sanitation 1000 meters from source Hand carry (Hofkes) ***7***	Developing world Dry sanitation 100 meters from source (one block) Hand carry (Hofkes; Howard) ***20***	Modern world camping trip Open defecation Bring water or gather from streams Hand carry (Author calculations) ***7***
Developing world Dry sanitation Yard tap Hand carry (Hofkes; Howard ***45***	Developing world Dry sanitation In house tap Not including productive uses (Hofkes; Howard) ***50***	Developing world Flush toilet Full amenities Not including productive uses (Hofkes; Howard) ***150***
Developing world Urban environment Flush toilet, leaky water system No effective metering (Walker) ***Up to 500***	Northern Europe Urban environment Best existing technology Metering, conservation commitment (Aquaterra) ***~110***	Europe Urban environment Older technology, No metering (Aquaterra) ***~155***
Future scenario Europe Urban environment Cutting edge tech Modest in-residence recycling (Author etimate) ***~95***	Future scenario Europe Urban environment Cutting edge tech Agressive in-residence recycling (Author estimate) ***~80***	Future scenario Europe Urban environment Cutting edge tech Utiltiy full water recycling (Author estimate) ***~40***
USA Urban environment Older technology Cool moist climate, outdoor watering (REUWS plus author calc) ***~300***	USA Urban environment Older technology Hot arid climate, outdoor watering (REUWS plus author calc) ***~800***	Future scenario USA Urban environment Cutting edge tech Metering, conservation commitment (Author estimate) ***~225***
Denmark - source 1 (ex. discrepancy) Urban environment Best existing technology Metering, conservation commitment Just residence? (Aquaterra, 2008) ***~122***	Denmark - source 2 (compare to 1) Urban environment Best existing technology Metering, conservation commitment Gross average? (UNDP, 2006) ***~210***	Alaska northern village Permafrost environment Special water adaptations for cold Full amenities including toilet Strong conservation incentive ***~78***

There is abundant data supporting the idea that our condition of being human defines just over 1% of our direct water consumption; our surroundings the other 99%. Regardless of how the extremes of viable or actual domestic consumption are defined (they could be stated as from ~5 to 783 lpcd or from ~7 to ~600 lpcd depending on sources), the spread constitutes an approximate 100:1 relationship. There is no single unifying number for domestic water consumption. The mosaic and composite tables of water consumption data presented here (and in more detail in chapter 17), while they do not provide a single one-size-fits-all answer, do allow for the viewer integration within a single eyespan the range of consumption numbers.

Endsheet

Last document page and back cover